

**FOREST COVER MAPPING FROM LANDSAT — MSS DATA
BY ANALOGUE AND COMPUTER ASSISTED TECHNIQUES
IN THE FEDERAL REPUBLIC OF GERMANY —
A FEASIBILITY STUDY**

**Inaugural Dissertation
for the obtainment of a Doctoral Degree
in the Faculty of Forestry of the
Albert-Ludwigs-University
at Freiburg in Breisgau**

**Presented by
Carlos Marx Ribeiro Carneiro
from Brazil**

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THE DATA
ANALYSIS AND COMPARISON
IN THE FEDERAL BUREAU OF INVESTIGATION
A FEASIBILITY STUDY



This work is dedicated to

my wife Jane, and

my son Christian Marx.

Printed with financial aid from the Brazilain Coordination
for Training Higher Education Personnel - CAPES

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Publication date of examination results: 18. 12. 1978.

ACKNOWLEDGMENTS

I wish to express my special thanks and deep appreciation to Professor Dr. Gerd Hildebrandt, head and adviser of the present study, who not only made it possible for me to pursue my doctoral work in his department, but who also gave me his guidance as well as his constant efforts, support and important suggestions during the preparation of this dissertation.

Acknowledgment is also extended to Professor Dr. Dr. h.c. M. Prodan, co-adviser of this study.

In addition, I would like to thank The Federal University of Santa Maria (UFSM) and the "Coordination for Training Higher Education Personnel" (CAPES) who provided me with the opportunity for realizing my studies in the Federal Republic of Germany. The UFSM supported me extensively in my doctoral training program, while CAPES granted me a fellowship (Process No. 1073/76) which made the development of this program possible.

I would also like to express my gratitude to Diplom Forstwirt Paul G. Reichert, Assistant of the Department of Photogrammetry and Photointerpretation, who helped me both in my work with the microdensitometer as well as in the computer assisted classifications carried out at the German Aerospace Research Center in Oberpfaffenhofen.

I offer my appreciation as well to Mr. Hilmar Dietze who worked together with the Cand. forest Ralf Kessler in preparing the Landsat MSS prints and transparencies.

Also, I am very grateful to Mr. Peter Uthoff as well as to the head of the Freiburg Forest Service. Mr. Uthoff provided me with access to the Forest service files, and through his deep practical knowledge gave me an understanding of the vegetation types in Test Area I.

Similar acknowledgments are given to the heads of the follow-

ing forest districts: Kirchzarten, St. Märgen, Titisee-Neustadt and the "Fürstlich Furstenbergischen" Forest Service in Neustadt. Access to their management files made possible the preparation of a very detailed ground truth in Test Area II.

Acknowledgment is given to Andy Burnham, a North American from San Francisco, California, for the review and corrections of the manuscript in the English language, as well as to all other friends at the Department of Photogrammetry and Photo-interpretation who helped in various ways.

Finally, I give special thanks to Jane and Christian for their patience and fortitude throughout the entire program.

Carlos Marx Ribeiro Carneiro

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1. INTRODUCTION

With the continuous development in the field of technology, more and more new devices and processes are being investigated which aim at updating methods and especially at speeding the acquisition of products. This increasing technical acceleration involves a strong tendency towards automation, since automation allows for quicker and cheaper final results and higher levels of productivity. Within forestry itself, and most importantly within the area of forest mapping, this tendency is becoming extremely noticeable due to the growing need for updated maps, which are fundamental to the monitoring of natural resources.

The history of forest mapping began in Europe around the end of the 18th century, and the first maps were simply the result of direct field work, containing the accuracies and inaccuracies inherent in such a form of investigation. These first maps were very incomplete in terms of floristic composition, and though they generally met practical forest requirements, they nevertheless often led to erroneous conclusions about the nature and structure of forest stands and thereby established a questionable basis for many forest operations.

With the first practical usage of aerial photographs, around the time of World War I, new techniques and instruments were developed for representing the correct nature of forest populations on thematic maps. These new maps were produced through photogrammetric methods and were of increased accuracy, since forest stands were observed from a greater altitude and interpreted through instruments which reconstructed the landscape both three-dimensionally and exactly.

The first successful evaluation of aerial photographs in forestry took place during the early 1920's. At that time, photographs in Germany were taken and evaluated from the Roggerburger Forest (1921), from the Nürnberger Reichenwald (1922) and from the large Forstrieder Park near Munich. As

early as 1923, The Canadian Forest Service established a special section of aerial photography for the purpose of forest inventory and mapping (HILDEBRANDT, 1966). Similar developments occurred soon afterwards in other European countries and the United States (HILDEBRANDT 1956, 1966); QUAKENBUSH, 1960).

After the advent of color and color infrared aerial photos in the 1940's and the improvement of color and color infrared films in the 1950's, the process of forest interpretation turned more dynamic due to the possibility of making more detailed inventories of the conditions of the forest population. Diseases, insect infestation as well as mineral and water deficiencies can all be more carefully determined, while the different vegetation types within the different forest layers can be better characterized throughout the seasons of the year. As a result, new possibilities opened up for the production of complex and refined forest management maps.

Also, through increasing progress in surveying techniques, many new sensors were developed - both photographic sensors such as multispectral cameras as well as non-photographic sensors such as radar and multispectral scanners. Moreover, this progress was accompanied by a diversification in data collection systems, with a greater emphasis being placed on orbital platforms.

At the same time, new qualitative processes of interpretation came about, based on already internationally accepted patterns of visual interpretation, as tone and photographic texture, form and characteristics of forest stands as well as size and environment; all of which adapt themselves more to the different types of imagery. In addition, some of these qualitative patterns, especially tone and photographic texture, were able to be quantified through the use of instruments as micro-densitometers, image analyzers and computers, which themselves had become increasingly refined and accurate.

Based on all of these developments, an increasing emphasis has

been given in the last few years to the study of data acquired from orbital platforms and especially to data received from Landsat (formerly ERTS). An effort is being made to obtain a table of perfect applicabilities from these data, which can be used in surveying the many natural resources as well as in deriving new keys to quantitative and qualitative evaluations. Ultimately, this effort is aimed at making the task of forest inventory and the mapping of extensive areas quicker and easier.

The extraction of forestry information from Landsat data seems to be an accepted technique for large area inventories (as partially verified by COLWELL et al (1973); KALENSKY (1974, 1976, 1978); HELLER (1973, 1976); HOWARD (1976); LAPIETRA and MÉGIER (1976); MOLERES (1976) BALTAXE and LANLY (1976); SAYN-WITTGENSTEIN and ALDRED (1976) among some others. However, the information and keys of interpretation tend to have a local or regional character due to the experimental characteristics still presented by the data and to the normal variability found in different forest populations grown under different climatic and topographical conditions.

Furthermore, various authors have obtained contradictory results and conclusions from these data. COLWELL et al (1973, 1974); BURGY et al (1974), NICHOLS et al (1974), HOFFER et al (1975a, 1975b, 1976), for instance, stress the importance of Landsat products. On the other hand, pessimistic conclusions are shared by MEAD and MEYER (1977), and SAGDEV (1978). A representative opinion, mentioned by SAYN-WITTGENSTEIN (1976, 1977) and HILDEBRANDT (1977a, 1977b) is that they "do not believe that any future large area surveys can go ahead without considering the possible contributions of satellites."

According to HILDEBRANDT (1976, 1977a, 1977b), "Information and data for decision makers, managers and forest services are only useful: if they meet specified required precision, if they are available soon after acquisition, if they are of relatively low cost and if simple evaluation and interpretation techniques are available." These four prerequisites, which

help to define the idea of usable information and data are generally fulfilled by Landsat data which makes them very profitable to forest resources inventories.

For repetitive forest surveys conducted at defined intervals of time (monitoring), it is necessary to have a thorough knowledge of how the data and the methods of data interpretation are related to the forest cover itself. Also, it is necessary to have a deep baseline of the forest types being studied, against which new data can be compared to measure the changes.

Yet in spite of all the great progress made so far in the field of forest mapping in Central Europe, and even considering the extensive management units, a deep knowledge of the relations between forest cover and satellite data is still lacking (see PLEVIN, 1978; DFG, 1977). Furthermore, it is important to remember that everyone who is actively engaged in evaluating forest resources, whether from the standpoint of long-term development planning, large regional survey or local management planning, requires information from time to time concerning the resource baseline, and that this information is gained in most European countries through forest evaluations which are done infrequently and from statistics which often show discrepancies even within the same country (as observed in FRAYSSE, 1977).

Based on all of this, the present study aims essentially at using Landsat data through qualitative and quantitative methods of interpretation, to examine the cartographic characteristics and relationships of a number of Central European forest stand types, as well as to establish the applicability of Landsat data to forest resources mapping when different methods of interpretation are applied.

2. BASIC CONCEPTS ABOUT THE LANDSAT PROGRAM

2.1. Earth Resource Technology Satellites: Landsat 1, 2 and 3

The satellite Landsat 1, launched on July 23, 1972 and officially retired on January 6, 1978, was similar in its basic and technical conception to the meteorological satellites of the Nimbus series. Its orbit was near polar with an altitude of approximately 915 to 920 kilometers, circling the earth from north to south every 103 minutes (i.e., 14 times per day). The satellite had an inclination in relation to the equator of $99,10^{\circ}$, and in every rotation its data collection systems gathered information from a strip of the earth's surface 185 kilometers wide. In each north-south pass, the spacecraft crossed the equator at the same angle (FRANCE, 1976).

The second satellite of the Landsat program was launched from California on January 22, 1975 and had the same technical orbital data on the same data collection systems as Landsat 1 (GFELLER, 1975; ZABEL, 1975).

On March 5, 1978, the third satellite of the Landsat series was launched and was equipped with an additional sensor: a thermal infrared scanner (10,4-12,6 micrometers) with the capability of sensing temperatures from -13°C to 67°C and with a temperature resolution of $1,5^{\circ}\text{C}$ and 240 IFOV (WHITMAN, 1978; FAO, 1978). The television system on Landsat 3 operates in the panchromatic region of the spectrum with a resolution two times greater than in the first two satellites (approximately 40 meters). And also, Landsat 3 circles the earth in a near polar sun-synchronized orbit (USA, 1976; COLVOCORESSES, 1976; RICE et al 1978).

Before the Landsat program, many manned satellites from the Gemini and Apollo missions collected data from the earth's surface with resolutions ranging from 9 to 60 meters. Yet unlike the Landsat coverage, the data from manned spacecraft was not repetitive and was confined to the lower latitudes (RABCHEVSKY,

1977).

2.1.1. Systems of Data Collection

2.1.1.1. RBV: Return Beam Vidicon Cameras

Landsat 1 and 2 were equipped with three RBV cameras to collect data within three different spectral bands from an area of the earth's surface corresponding to $185 \times 185 \text{ Km}^2$ (though the RBV cameras on Landsat 1 were turned off one month after launching because of technical problems). These cameras store the collected data in the photosensible part of the RBV and these data are electronically scanned in such a way that new images can be produced after the registrations are transmitted back to earth. The RBV system on Landsat 3 is significantly different from the systems on the previous satellites, since two panchromatic cameras produced two side-by-side images rather than three overlapping images of the same scene.

2.1.1.2. MSS: Multispectral Scanners

The MSS system covers the same geographic area as the RBV, though in four different spectral bands rather than three (see table 1).

Table 1. Spectral bands of the Landsat Multispectral Scanner

Spectral bands	Band width - micron
4 - Green	0,50 - 0,60
5 - Light red	0,60 - 0,70
6 - Dark red - Infrared	0,70 - 0,80
7 - Infrared	0,80 - 1,10

During the satellite's orbit, an oscillating mirror scans the area under the spacecraft orthogonally to the flight direction. The energy reflected from the scene is scanned by means of an optical-mechanical device that directs radiation to detectors which transform the radioactive intensity into electrical video signals. The scanner registers the scene in four bands simultaneously, and the data are electronically calibrated.

With the MSS, the possibility exists for interpreting single spectral bands or combinations of bands, thereby producing panchromatic or infrared effects of the same scene.

Every image produced by the MSS is formed by a number of parallel scanning lines and every parallel line is the result of a certain number of pixels (i.e., picture elements). With the radiometric resolution of the MSS, the area of the earth's surface covered by each pixel has been calculated to be approximately 79 x 79 meters (a problem to be discussed later in detail), while a complete MSS CCT-scene (185 x 186 kilometers) contains a total of 2340 scanning lines each composed of 3000 to 3450 bytes of video data. A byte is formed by 8 bits and every 8 bit-bytes corresponds to one value of radiation. Image registration depends directly on this 8 bit precision - which is to say, only a maximum of 2^8 (256) grey tones can be distinguished - though in reality this theoretical capacity is not fully used.

2.1.2 Landsat Data Products

In the NASA Data Processing Facility (NDPF), three types of Landsat products are essentially available (though others are also currently being researched). These three products result from the following processes:

- | | |
|-----------------------|---|
| Bulk Processing: | This produces "System Corrected Images" - images where the basic radiometric and geometric corrections have been carried out. |
| Precision Processing: | This provides "Scene Corrected |

Images" - images with additional geometric corrections.

Special Processing: This involves registering images in a Computer Compatible Tape format (CCT). (see BENDIX, 1971; USA, 1973).

In the present study, bulk and CCT products were used.

The most important parameters for evaluating the quality of Landsat products are:

Resolution power
Geometric fidelity
And radiometric fidelity

The mathematical-physical model for correcting each of these parameters was developed by NASA (1972).

2.2. Geometric and Cartographic Accuracy of Landsat-MSS-Data

Images collected from the Landsat MSS show different geometric characteristics when compared with aerial photographs. Many considerations regarding the geometrical properties of Landsat data and related technical elements can be found in NASA, 1972; KOEBL, 1973; BRASIL 1975; and ASP, 1975. Yet, considering the very high altitude from which Landsat products are collected, distortions due to relief practically do not exist. Many corrections are made at the receiving stations, making possible the obtainment of high quality products - or in other words, the final Landsat MSS image is virtually like an orthophoto.

The success of the perfect positioning of pixels in satellite data depends to a great extent upon the possibility of identifying and quantifying the sources of distortions and then minimizing these distortions during the phase of the image's production. Many distortions result from recognizable errors and these errors might be characterized as follows:

External Errors: for example, changes in the satellite's

orbit

Internal Errors: for example, modifications in the sensor's calibration

Production Errors: for example, errors in the transformation or copying of images

In turn, these errors produce two main types of image distortions: namely, geometric distortions and radiometric distortions.

For a more detailed description of the sources of distortions in Landsat products, see NASA (1972).

In short, however, it is worth while to remember (as pointed out in ABIODUN, 1978) that satellite imagery can offer a very high degree of accuracy at a low cost when compared with airphotos. Indeed, the basic cost of satellite imagery is 200 times cheaper than black and white airphotos at a scale of 1:24,000 and 50 times cheaper than color infrared airphotos at a scale of 1:120,000.

3. LITERATURE REVIEW OF THE GEOMETRIC AND CARTOGRAPHIC ACCURACY OF LANDSAT - MSS - DATA

As highly recommended by NIELSEN (1971), all pertinent information which can influence the results as well as the original observations of an author should be included in a research work. This increases the value of the report, making it profitable to a larger number of users.

Based on this recommendation, a literature review of the current study will next be presented.

HELLER (1973), cites that "the positional accuracy of ground locations on the first Landsat images, when compared to first-order maps, presented problems. On system corrected images (bulk), longitude tick marks have been displaced as much as 200 meters.

The displacement of identifiable points on Landsat images in a forestry test site in Georgia was 520 meters for bulk images. On precision images, the templates showed a displacement of 300 meters".

However, as stated by some other authors (COLVOCORESSES, 1974; USA, 1976), the positional errors (RMS) of points on a properly controlled image are less than 80 meter instantaneous field of view (picture element) of the scanner. Such accuracy is attributed to the stability of the scanner and spacecraft and to the corrections that are being made by NASA before each image is printed. The image is in fact formed on a cylindrical surface which can be defined as a specific map projection.

Moreover, the projection is mathematically definable and thus has the potential of developing into an automatic mapping system in which the picture element (pixel) can be discretely related to its position on the figure of the earth.

The geometric fidelity of the MSS system is a little inferior to the RBV system; however, as observed by SHEFFIELD (1976),

the MSS radiometric fidelity is much better than that of the RBV and this is important in all work where quantitative measures of relative spectral reflectance are involved, and is specially necessary in multispectral classification.

McEWEN (1973), added that "the minimal limit for measuring the size and shape of an object was 200-400 meters, depending on the contrast. However, for measuring the real spectral characteristics and shapes of an area hundreds of meters would be necessary".

KRATKY (1974), states that the size of a ground scene covered by images taken from Landsat is too large to disregard inherent limitations of a cartographic projection used for the precision processing of the images.

"In this case of the standard UTM projection adopted for Landsat project, some of the scenes are extended beyond the zone boundaries and the distortion then exceeds the cartographic specifications usually expected with single zones".

An analysis of these cartographic aspects shows the type and magnitude of resulting geometric changes for both types of imageries produced by the Landsat.

According to SCHOONMAKER (1974), the United States Geological Survey analyzed Landsat images as a basis for an image-format map series. In this study, the geometric characteristics of the MSS images were evaluated at three locations: northern, middle and southern parts of the US east coast. Ground scenes imaged at different times of the year were examined. Control points were measured from large scale USGS topographic maps. Results showed an rms error in position of about 200m and a systematic pattern in the residuals. The geometric qualities of the MSS images and the Landsat orbit are suitable for a 1:500,000 scale image map series.

SOUZA and BATISTA (1974), highlighted the geometric accuracy of these images based on parameters like, satellite orbit attitude (high stability), the environment of the orbit and

the sophisticated system for its correction.

The surface of the earth seems to be flat because of the spacecraft altitude and so the parallax distortions are shortened. They also emphasized that the spatial resolution presented by the system was compatible with mapping at reconnaissance levels (see CARNEIRO, 1975).

For WONG (1975), the potential application of the RBV and MSS images in cartographic mapping is limited by resolution rather than by geometric fidelity. A bulk MSS frame could easily be processed to meet the NMAS requirements of 1:500,000 scale mapping. In digital processing, a relative positioning accuracy of $\pm 55\text{m}$ should be attainable. BÄHR and SCHUHR (1974), working in northern Germany in similar conditions found a value of 106m.

To FISCHER et al (1976), cartographically, the data from Landsat have far exceeded expectations and, properly proceeded, are proving more timely and in other ways superior to conventional line maps for a variety of uses.

Geometric distortions for HELLER (1976), are inherent in Landsat film products and computer compatible tapes. These distortions greatly influence the plotting accuracy of boundaries and extraction of area statistics (see also COLVOCORESSES, 1973).

The major sources of geometric distortions are skew, aspect ratio, mirror scan rate, scale distortions and topographic variation within the scene.

Although many variables will affect the accuracy of geometric correction, techniques currently available are capable of producing images geometrically corrected to approximately sixty meters.

For TRINDER and NASCA (1976), it appears possible to extract sufficient cartographic details from channels 5 and 7 for mapping at the scale of 1:250,000; Bands 4 and 6 have no

additional information to offer that has not already been given by bands 5 and 7. However, in a quick look they stated that forest cover is evident in every band. That disagrees with many other papers (see chapter 4).

Using identifiable points on maps at 1:250.000 and 1:100.000 as control points, an adjustment of the whole image using a 12 parameter polynomials results in a circular standard error of 61m on the ground for well defined points (vector error of 86m). This is larger than the map accuracy standards for 1:250.000 of 78 meters.

DOYLE (1975) and KANEKO (1976) say, however, that corrected images with a geometric accuracy of approximately 1 pixel can be recorded on computer compatible tape (CCT), allowing accurate temporal change detection and multispectral classification to be performed. Maps meeting NMAs at 1:250.000 to 1:125.000 scale can be produced from the digitally processed data. Film data with a geometric accuracy of 1 to 2 pixels can be combined or compared with 1:250.000 or 1:500.000 scale cartographic or land use maps.

Most importantly, it should be emphasized that "although not designed primarily as a mapping tool, data from the MSS on Landsat have demonstrated surprising good geometric characteristics (COLVOCORESSES, 1976).

Finally, it is worth while to remember that a picture element recorded on the Landsat CCT represents a ground area as a 57m (E-W) by 79m (N-S) parallelogram inclined about 12 degrees east of north, that provides a ground dimension of about 0,45 ha; visually, the smallest areas that can be correctly identified on high quality imagery (color composites) is about 5 - 10 ha. (HOWARD, 1976, PARK and MILLER, 1978; FAO, 1978; among many others).

4. APPLICATIONS OF LANDSAT DATA TO FOREST COVER

There are two ways of using Landsat products: the first is the traditional one - namely, a method of visual interpretation, applying the main patterns of aerial photointerpretation. The second, developed more recently, is a method of machine interpretation. In this second case, a number of processing devices are employed in order to simplify and automatize the entire approach to interpretation and in order to make this approach operational.

Computer Compatible Tapes (CCT's) are the products offering Landsat users the best spatial resolution and the most precise spatial information than can be viewed in the form of images. These images are photographic products and are limited to a number of shades of grey that can be presented and interpreted by the human eye. Ten to sixteen levels are common on most images, though the original data can contain up to 64 spectral levels per spectral band. Also, each 185×185 kilometer Landsat scene is made up to $7 \frac{1}{2}$ million digital pixels per spectral band. Each pixel contains, as already seen, the radiance value for an earth surface area of about 57×79 meters (GFELLER, 1975; COLVOCORESSES, 1976; HEASLIP, 1976).

4.1. Visual Interpretation

a. "For two analyses, bands 5 and 7 identify vegetation best when combined on an optical combiner. Band 4 does not seem to furnish additional information and could be left out of the combined image. Band 6 does not identify water bodies and streams as strongly as band 7, but it often enhances changes in tree vigor more accurately than band 7 "(see also CARNEIRO and SILVA, 1976)

b. "For single band analysis band 5 enhances vegetation more than any other band. Band 7 enhances bodies of water, rivers and streams best "(see USA, 1973)

c. "All four bands are currently being used in developing computer signatures of forest land use types.

d. Forest vegetation shows up best in spring, fall and winter in temperate zones on band 5. In semiarid areas summer imagery has greater contrast than winter imagery if major rainfall occurs in winter.

Band 7 can reduce contrast between snow on the ground and trees. The very high reflectance from snow obscures color differences in vegetation caused by stress. Band 5 is also useful for identifying snow boundaries. The high infrared reflectance in bands 6 and 7 and uniformly low red reflectance in band 5 makes it difficult to separate forest from other vegetation (except agricultural fields).

Therefore, Landsat imagery is less useful in summer than at other seasons in temperate zones where rain falls throughout the growing season.

e. Forest/nonforest type separations can be made when forests are young to mature but are difficult to make when forests are in a transitional state such as brushlands, newly planted stands, or partially cutover stands.

f. Long, straight objects more than 100 m wide that infringe on forest land can usually be detected. These include power lines, wide roads or freeways, and clearcutting in long strips.

He stated finally that for countries like Germany, France, England and others, where intensive forestry is practical, the forest manager would benefit by having one good Landsat image of his property for planning purposes. These images would provide him with a broad synoptic view, showing him his entire forest holdings in one map-like view. However, these images will be of higher utility for areas of extensive forest management" (HULLER, 1973).

Van ES (1974), conducting a research study in India concluded that one of the best ways to visually interpret Landsat MSS

images, was through an Additive Color Viewer. In this study, the best filter-band combination for interpretation of the images was either:

- (a) band 5 with a red filter, band 6 with a green filter and band 7 with a blue filter or,
- (b) band 5 with a blue filter, band 6 with a green filter and band 7 with a red filter.

Because of the small scale used (approx. 1:1.300.000 enlarged in the viewer's screen) areas smaller than 20 ha could not be measured.

It was also found that the best contrast was obtained when the images were illuminated with an intensity of between 4,5 and 7,0 on the I²S dial. Band 4 was not useful in the interpretation.

Some of the results obtained can be seen in table 2.

Table 2. Comparisons of area determinations of forest stands between airphoto maps and Landsat images (van ES, 1974).

Photomap			Landsat map		
Type	Area in ha	%	Type	Area in ha	%
S(sal)	64562	42	S(sal)	76125	50
Msp	39531	26	Msp	32812	22
Ms	24625	16	Ms	21375	14
M+P+Mp+					
Mw+Mwp	23750	16	M+P	21719	14
Total	152.468		Total	152.031	

Ms = dry deciduous forest; Msp = mixed deciduous forest

M+P= combinations of the types indicated on the photomap as M, P, Mp, Mw and Mwp.

The boundaries of the main forest types were readily visible. The difference of 437 ha between the total areas of the two maps is, in the author's opinion, extremely small and should be seen as a chance exception.

The resolution of the imagery was, however, not good enough to distinguish small patches of forest. If different forest types are intermixed in small patches, the image becomes mottled, and it is then possible to discern individual patches larger than 20 ha. only if there is a large difference in tone between the types. Landsat imagery is most valuable for an overall idea of a large area. If the imagery had been available during the preparation of the interpretation map of the Doon Valley, it would have been of considerable help in supplementing the conventional photography. An improvement in the resolution of Landsat imagery from the theoretical 75m. to 20 - 30 meters therefore seems desirable.

In this case, the problem was that the author worked with a very small scale and could not arrive at the best conclusions. This areal limit of 20 ha. is indeed doubtful and can be improved by using a larger scale, for instance, 1:200,000.

ROHDE and MOORE (1974), working over an eastern Pennsylvania area stated that Landsat images indicated that forest defoliation is detectable from satellite imagery and correlate well with aerial visual survey data. It now appears that two damage classes (heavy and moderate light) and areas of no visible defoliation can be detected and mapped from properly prepared false color composite imagery by human interpreters.

Tonal contrasts between heavily defoliated areas and undefoliated areas present a simple dichotomous decision for the interpreter, and in the case of heavily defoliated areas, Landsat 1 imagery provides an especially clear means for detection as well as ultimately for mapping. The entire process of interpreting satellite imagery can be most easily accomplished through the use of multi-date color composites prepared from MSS band 7.

According to NIELSEN and WIGHTMAN (1974), "although Landsat imagery permitted mapping of the boundaries of some of the major forest types of Canada, its use in this application is more limited than had been expected. A significant factor in this limitation was the inconsistency of the imagery (see also BRASIL, 1977). Differences in quality were very pronounced among black and white as well as among color scenes. These qualitative differences were due primarily to a combination of variables related to image reproduction and date of data acquisition".

In this case, better conclusions could not be made due to the poor quality of the materials and methods used.

In an exploratory study using MSS bulk images of eastern Brazil (NOSSIER et al., 1975), the synoptic view offered by each MSS frame enabled a reconstruction of the vegetation cover. As a result, it was possible to establish both a natural cover history of the area as well as a general methodology for this form of mapping as a whole. Furthermore, it was found that a combination of bands 5 and 7 provided the best tonal contrast (amplitude) and was consequently the most useful information for interpretation. The drainage network was applied for spatially orienting the interpretation overlays and although the micro-scale of 1:1.000.000 did not allow for the recognition of forest types, it nevertheless made the task of tracing boundaries an easy one.

With regard to the applicability of Landsat visual interpretations versus non-manual interpretations, HELLER (1975), stated: "Classifications can be done more effectively by computer, but photointerpretation produces equally accurate results. Choice would depend on availability of trained people and equipment."

He added that managers of large ownerships (more than 4000 ha.) would benefit by using Landsat enlargements for planning. Color composites are preferable and scales of 1:125.000 to 1:250.000 are most useful. For black and white enlargements, the best band is MSS-5, and enlargements to scales of 1:125.000

can be effectively used for high-altitude aerial navigation, especially in remote areas where existing maps are inadequate.

Finally, he observed that on 1:1,000,000 scale color composites, interpreters consistently distinguished forest and non-forest classes with 96 per cent accuracy, regardless of the combination of seasons used. Interpreters could not classify Level II (species) to acceptable accuracies. Pine was identified with 60 to 65 per cent accuracy, hardwood with 50 per cent; other classes ranged from 7 to 85 per cent.

On computer classification, Level I was similar to human performance, while Level II had better performance than interpreters.

Concerning the mapping costs, NITHACK et al (1975), and CARNEIRO (1975), emphasized the mapping costs when compared with traditional methods at the same level of detail. For the first author, based on the spectral behaviour of the different soil covers, a combination of images of bands 5 and 7, taken at different seasons, can permit, with a basic ground truth, a very good subdivision of the main forest and agricultural types.

Using a visual interpretation procedure, CARNEIRO and SILVA (1976), stated that at a reconnaissance level the MSS Landsat 1 images were undoubtedly of high utility in mapping forest and non-forest vegetation cover. The 1:250,000 scale imagery was the best for this purpose but the 1:500,000 scale showed details quite clearly and was comparable to the other scale imagery. Channel 5 was the most informative.

The tone or brightness scale seemed to be useful in separating natural forest cover from artificial vegetation cover; however, the stand shape, in this particular case, proved to be very informative. The "man made" stands presented well defined geometric shapes while natural ones did not.

The photographic texture did not show additional information

and was not considered as a good interpretative pattern since the brightness was quite similar.

On another study, this one involving airphotos of India, van ES (1976) divided the stratification of a forest into 12 classes, and compiled a forest map that would be used as a "ground truth". That map (1:25,000) was afterwards reduced to 1:100,000 and the 12 classes were reduced to 4; 9,5 inches, 1:1.000.000 scale diapositives were used, 70 x 70 mm. pieces of these being cut from the transparencies for the interpretation of the area of interest.

The transparencies were studied in an Additive Color Viewer. The scale of interpretation on the viewer's screen was approximately 1:150,000, and was afterwards enlarged to 1:1000,000 by an optical pantograph.

In this case, the most useful band-filter-exposure time combinations for the image interpretation were:

- (a) band 5 with a red filter and band 7 with a green filter for an exposure of 23.2.73, illuminated at setting 7 - 9, combined with
- (b) band 5 without filter and band 7 with red filter for an exposure of 12.12.72, illuminated at setting approx. 2.

The results were similar to those formerly obtained (van ES, 1974).

KLANKAMSORN (1976), working in Thailand with Landsat data at a scale of 1:5000,000, observed that the best forest interpretation was accomplished when the images of bands 5 and 7 were used. The best photographic patterns for forest recognition were texture and tone contrast. In the future, emphasis will be given to the location of forest stands for determination of watershed areas of the whole country.

A very good contribution to a better understanding of the potential usage of these images has been provided by JENSEN

and MEYER (1976). Although the imagery was enhanced using both a color additive viewer and a density level slicer, the results of these experiments were less successful than anticipated. In fact, forest/non-forest, hardwood/conifer, and upland/low-land types could not be reliably distinguished in Minnesota and the grassland, shrub/grassland, ponderosa pine forest, pine woodland, and agricultural types were in some cases indistinguishable on the Montana imagery. These studies concluded that there were several reasons for misclassifications. First, the forest types occur at varying levels of crown closure resulting in variable signatures, even for a single forest type. Second, it was found that many of the vegetation types had similar spectral signatures or grey tones, and thus were difficult to distinguish. Furthermore, when interpreting these subtle differences in tone, the classification was highly dependent upon the visual acuity of the interpreter. And finally, in the process of copying the enhanced image, the quality of the imagery was reduced and thus there was a reduction in information content.

It should be adequate to mention the conclusions resulting from a FAO pilot project for monitoring tropical forest cover and presented by BALTAXE and LANLY (1976): "the most practical approach seems to be to start by interpreting available satellite imagery by conventional means in the greatest possible detail in terms of vegetation classification. At best this will yield a compilation at 1:250,000, since greater enlargement of imagery tends to blur boundaries and therefore does not increase extractable information. Final compilation at the country level is foreseen at a scale no larger than 1:500,000, so the size of areas which can be delimited at 1:250,000 will constitute no constraint on detail.(see also FAO, 1975).

Finally, regarding the economical application of Landsat products, THORLEY and HOOD (1977) cite: "The Washington State Department of Natural Resources is utilizing Landsat data for a Western Washington Forest Inventory (10 mil. acres). While this inventory could have been accomplished by standard methods

within two years at an estimated cost of US \$ 2,0 million, the current estimates indicate that using Landsat data will allow a comparable inventory to be completed in one year at a cost of approximately US \$ 200,000."

By analyzing the many results and conclusions presented in this section, one can conclude that the applicability of visual interpretation to forest resources mapping and inventory is a very positive one. Photographic tone, texture and shape are the most applicable patterns of interpretation.

The scale 1:250.000 seems to be the one preferred by the majority of interpreters.

Interpretations carried out on color viewers seemed to present the best results: that is, interpretations of color images were more operational.

The best band combination was obtained when combining images of bands 5 and 7.

The advantage of multi-temporal images upon singles images was not clearly proved by the above mentioned studies.

4.2. Computer Assisted Interpretation

Automatic analysis is a machine process involving the use of computers or other instruments in order to produce map-type output, statistical graphics and tabulations, as well as other forms of information.

As stated by KUHLOW and FISHER (sd) "to extract the maximum amount of information from digitized data, both man and machine must be properly programmed, educated and dedicated." This can be perfectly visualized in figure 1.

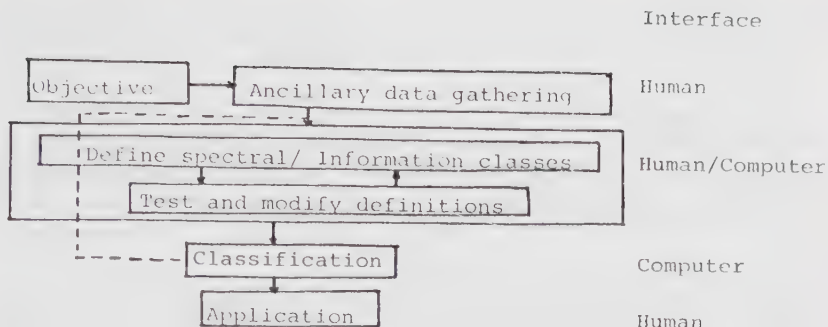


Figure 1. Generalized flow chart of the sequence of steps used in analysis. The column on the right indicates if the interface is principally human or computer (see also MROCZYNSKY, 1976).

Classification, as observed on the last figure, can be defined as the process in which a set of rules is used to assign each ground resolution element to one of several classes by machine or human methods. In the case of a human photointerpreter, classification extends results obtained in local known regions to surrounding unknown regions. Either classification method requires the use of selected characteristics. The photointerpreter commonly uses color or tone, texture and shape to identify similar regions. In computer classification of Landsat data, the magnitudes of the four pieces of spectral information are used as characteristics. It is assumed that two regions on the earth which are seasonally identical will have either an identical or a very similar set of numbers (spectral signatures). Regions which differ should have different signatures.

Computer classification eliminates the repetitious judgement of a human operator and increases the detail of the classification. Because of the magnitude of the data, a human operator could not possibly individually evaluate and classify the approximately 7,5 million ground resolution elements of a Landsat scene. (LAWRENCE and HERZOG, 1975).

For a given sensor the images in all the bands are spatially identical.

In the Landsat mission, there are two ways for the acquired MSS data. First, the scene is produced directly on a magnetic tape and the data come directly to a computer. Second, the data are produced in a photographic image form.

In the last case, the images have first to be digitized before going to the computer (practically used only when the possibility does not exist for use of the original data).

According to PRESTON (s.d.), this digitisation is the process of converting the photographic density of very small areas of the image to a numerical value. Typically, a photo may be digitised into a million bits. The measurement from each band has to be assembled into an n -dimensional measurement vector (n -dimensions of the vector are the n -density values).

This measurement vector is sometimes known as the density signature. After corrected, this density signature is transformed in a spectral signature. The last measurement vector is used in a number of automatic analysis routines to identify the contents of the image. These analysis routines fall into two basic categories: supervised and unsupervised.

Supervised methods.

Are those methods that require continual operator intervention to control their running. To identify an unknown measurement vector it is given to a classifier, which then classifies it as belonging either to a class or group of objects defined in the classifier. The classification is based upon a decision rule constructed in the initial phase of the analysis (see also HEASLIP, 1976).

The vectors from the same type of area tend to be nearly the same and form a cloud or cluster of points.

The construction of the pattern classifier involves dividing

measurement space into decision regions - each region being one of these clusters which represents a particular ground type or class.

To construct a pattern classifier, decision surfaces or decision areas have to be determined. Then some decision rule has to be devised that can be used to decide into which decision area a sample should be classified.

The position and extent of these decision areas are found by using a set of samples known as the training set. The initial clusters constructed from the training set define the position and extent of the decision regions. The training samples are measurement vectors taken from a collection of known areas which should contain all the classes to be identified.

This use of a known set of samples at the beginning of the analysis is one of the main characteristics of supervised learning.

When the clusters have been established from the training set, it is often easier to construct a classifier by defining the boundary separating the cluster. Unknown samples are then classed depending on which side of the boundary they lie. Mathematically, this is called setting up the discriminate functions, namely those functions used to discriminate the decision area to which an unknown sample belongs.

These discriminant functions are the mathematical equations used to describe the decision areas.

Within the area of supervised analysis a number of problems can be found:

- First, there is some uncertainty concerning the true identity of the training classes or the ability of these training classes to represent an entire area of classifications. This can be overcome by using Adaptive Methods; i.e. methods which constantly modify the decision area by evaluating the results of initial classifications.

Also, Cluster Analysis can be applied in order to eliminate the need for training samples.

- Second, clusters may overlap within the measurement space, thereby causing difficulty in discriminating the boundaries between clusters. This suggests the need for decision rules which identify one class as being "more likely" than others.
- And third, data may not be assignable to any class, thus suggesting the need for a special class into which all unidentifiable samples can be placed.

In most cases, the form of the applied mathematical functions is assumed to be known: i.e., the equations are known. Only certain parameters or constants of the equations are calculated by using the training set and such methods are known as parametric methods. Methods for which not even the form of the function is assumed are termed non parametric and are very difficult to implement.

The general parametric assumptions used in remote sensing define data as multivariate, normal and gaussian. This enables simple statistical methods to be used to set up the functions and allows the cluster distribution to be characterized by the mean and covariance matrices of the training samples.

Using these techniques it is possible to arrive at a maximum likelihood decision rule. This rule classifies a measurement vector as belonging to the decision area for which its probability of belonging is greater than belonging to any other decision area -with an additional proviso that this probability is greater than some threshold value to reject any sample not really belonging to the class. Such reject samples come from fences, roads and isolated buildings. The way this threshold is set is to put the training samples back through the classifier they have just been used to set up. The parameters of the classifiers can then be adjusted to reject, say 5 per cent of the samples. This usually ensures the most of the future samples that do not really belong to a given class are rejected.

Unsupervised methods

These start with the raw data, put them through a classifier and the output of these data is a map. The computer divides the image into a number of groups or homogeneous areas on the output map and afterwards a small area of the data can be selected and compared to the ground truth data of the same area.

Two main methods of clustering are: sequential clustering and k - means clustering. These work well if the clusters formed are reasonable spherical, but if the clusters are stringy then a different approach is needed.

Sequential clustering - is a one pass operation, i.e. the data are read once and assigned to a cluster or rejected. This has the disadvantage that samples passed over cannot be re-examined to see if they form another cluster. Each point is taken in sequence from the data set and examined only once. The operator can define a maximum number of clusters to be formed and if this number is exceeded some clusters are merged, or dropped if they contain an insignificant number of points.

In k - means clustering a number of arbitrary cluster centres are chosen by some means. The entire data set is then grouped around these centres using some statistical parameter, such as minimum Euclidean distance, to assign the data points to a particular centre. All of the points associated with one centre are used to calculate the new centre of the group which is then used as the input to the next run and so on until the centre remains in about the same place between runs. Problems arise due to the arbitrary nature of the starting points and from choosing a fixed number of groups to force the data to fit.

Microdensitometric Analysis

Microdensitometric analysis is not a method for producing map-type output, but rather, it is a method for "electronically reading" a section of an image. Such an electronic reading consists of transforming the tone densities of a given image

into graphical output - what are called microdensograms - and these microdensograms are then used as the basis for either manual or automatic interpretation.

Since a microdensogram is a statistical form of information describing tone densities in terms of maximum, minimum, mean and standard deviation, the process of interpretation inevitably involves establishing differentiations through the use of statistical procedures. Such interpretations are very important, especially since they lead to a better understanding of how manual methods of interpretation can eventually be automated.

4.2.1. Practical Applications of Supervised and Unsupervised Methods

For KALENSKY (1974), any task of computerized thematic mapping from remotely sensed data consists of four basic steps: preparation of input data and selection of classification procedure, digital image processing, display of results, and accuracy analysis.

At the first stage, the software is very important. For this study the software package consisted of computer programs for reading the tapes, data formatting and calibration, calculation of class statistics, scene classification, recording the thematic (classified) tape and display of results.

In the above mentioned study, Computer Compatible Tapes (CCT) were preferred for the following reasons:

- a. Analysis of seasonal changes requires multivariate correlation of several sets of Landsat multispectral images. This is very difficult and slow by visual interpretation.
- b. CCTs are not subjected to image degradation due to photographic process and reproduction.

- c. Digital images printed in CCT form direct input into computerized image processing system.

In this case, only spectral signatures were used.

By comparing the results of single-date and multirate classifications, two interesting conclusions can be drawn. First, multirate classifications yield a cleaner image (i.e. one with a lower noise level) since disturbing factors which vary from date to date and affect only a small portion of a class are eliminated (for example, system flows, surface moisture patterns, cultivation patterns, etc.). And second, multirate classifications offer a significantly increased consistency in accuracy since single-date classifications are obtained from a widely fluctuating source of data.

As to the display of results, line printouts present a clear disadvantage because of their geometric distortion and the fact that only 3000 pixels can be printed on a page. Considering that one Landsat scene contains 7,360,000 pixels, close to 2500 pages of computer printouts would be needed to display the classification results. The best solution is to record the thematic data on magnetic tape and to reproduce them by a digital film printer (CBS, 3M, DICOMED, PRAKLA, SEISMOS).

Correlation of ground truth with spatial patterns in the Landsat images is more difficult due to the averaging effect of large pixels on the spatial variation within the classes. As a consequence, most of these image classifiers are based on spectral signatures only. However, a combination of the spatial and spectral signatures in a single Landsat classifier yields a significantly increased classification accuracy.

The multirate composites provide the best display of ground classes because they are free of temporal changes of information which vary from one scene to the other as a function of the date of Landsat pass. Thus the changing pattern of field cultivation, surface water and image noise are greatly reduced on the multirate composite. It can readily be distinguished

by its cleared appearance from the single-date maps. Its ground resolution, on the other hand, was degraded due to the necessity of registering twelve images with resulting discontinuity in the reproduction of narrow objects (small rivers and roads).

KALENSKY and SCHERK (1975), studying the accuracy of forest mapping from Landsat computer compatible tapes, used ground truth for supervised classification and accuracy analysis data provided by medium scale aerial photography and forest cover maps and supplemented this information with spot field checks.

Classification accuracies were calculated in the form of confusion tables, though while the confusion table is an accepted way to express classification accuracy, it is somewhat inadequate for the expression of mapping accuracy, i.e., the error in class location on a map. Such error must combine the omissions and commissions in one summary measure since it must reflect the change in class pattern due to losses (omissions) to, as well as additions (commissions) from other classes (see KALENSKY and WIGHTMAN, 1976).

From these studies a very important conclusion was made: single data from bands 5 and 7 have presented a very good accuracy both in the mapping and classification.

For forestry purposes (mapping) it was similar to using multi-date of bands 5 and 7 of three different dates.

Working with digital data, LAWRENCE and HERZOG (1975) concluded that in general both stand density and tree species were significant in defining spectral signatures in five forest classes studied. They were to separate lodge pole pine from douglas fir in contradiction to HELLER (1975).

HELLER (1975), applying Landsat 1 MSS images in forest inventory, states that the value of these images for this purpose is affected by the positional accuracy of points within the

image, particularly when timber stands, sample plots, or other specific areas of interest are to be located precisely. For example, location of a perfect square of 4 hectares (10 acres) stand of timber requires a positional accuracy of at least ± 120 meters. Relation of a circular 0,4 ha. (1 acre) permanent sample plot requires a positional accuracy of only ± 30 meters. Location of a 100 meter square sample, randomly selected and identified on an overlay, as called for in the original experimental design for this study, required positional accuracy of ± 50 meters.

The small size of 4047 ha. of the study is no problem to a computer using digital data, but it does hamper the human interpreter trying to identify specific data points on 1:1,000,000 - scale Landsat imagery and consequently there was no statistically significant difference in results between the two seasonal images.

Results showed that these images, in this case, were more useful as a device for Level I land use classification (regional).

In a further analysis HELLER (1976), added that Landsat imagery has proven useful in delineating forest land from non-forest land when imagery at the proper time of the year is used for interpretation.

Although it is evident that detailed forest type mapping by species cannot be accomplished consistently with Landsat data, stratification of forest stands into strata related to density class, condition class, age class, etc. may be possible with controlled clustering techniques.

Research is needed to define the relationship between Landsat spectral signatures of forest stands and such parameters as slope, aspect, elevation, stand densities in terms of crown closure and basal area, size class, age class, and timber volume. In most forested areas, the correlation of spectral signatures with parameters related to stand conditions will vary as a function of phenology and time of the year. Definition of

these correlations will aid in specifying a statistical analysis approach with clustering techniques and will provide guidance as to the level of detail which can be extracted from Landsat data.

MRO CZYNSKY (1975), studying the North American central hardwoods, concluded that computer assisted Landsat classifications do have a great application to the management of these forests. General land use classifications can be provided at a greater level of detail and certainly in a more timely fashion than conventional techniques.

A Landsat satellite providing current synoptic coverage can provide data which is unfeasible to collect and interpret with conventional photographic sensors. Certainly for monitoring the change in the forest land use base map, this technology cannot be equalled. However, more research is required to fully understand the spectral characteristics of the ground scene and how these vary over time.

In the last years, emphasis has been given to the use of orbital data in a multistage concept to forest inventories.

The Forestry Remote Sensing Laboratory at the University of California at Berkeley, according to THORLEY et al (1975), performed a similar timber inventory based on manual and automatic analyses of data from Landsat 1 and from supporting aircraft to provide multistage sampling. According to Langley's Model (1969, 1976), a three stage sampling design was used; automatic classification of Landsat data tapes and selection of primary sampling units; the second stage involved acquisition of large scale aerial photos over selected primary sampling units and selection of photo plots based on manual interpretation, and the third stage involved visiting selected photo plots on the ground and selecting trees to be measured for timber volume. The total volume estimated was 2,44 billion board feet with a sampling error of 8,2 per cent.

A point-by point comparison of computer classified Landsat 1

data with manually interpreted low altitude photo plots indicated no significant differences in the overall classification accuracies.

ELLEFSEN and PERUZZI (1976), in analyzing digital data of Landsat with computer assistance, demonstrate that such data can yield reasonably satisfactory results. This is especially so if the goal is regional, state, or nation level change monitoring rather than the parcel-level measurement usually required by local urban planners. The mapped changes can be either computer-to-manual or computer-to-computer and may be either used alone or as a compilation tool by manual air-photointerpreters in conjunction with visual imagery. A more practical approach will surely be a complementary interaction of the two.

According to HOFFER et al (1975b), sometimes an unsupervised classification can be more useful than a supervised one; an unsupervised approach can usually be more satisfactory when analyzing MSS data obtained over wildland areas. This is due to the difficulty of knowing how many spectral classes are included in a single species or cover type. For areas that are spectrally complex a new technique was developed - the modified cluster.

HOFFER (1976), demonstrated that geometric correction and scaling of multispectral satellite data using digital techniques allows accurate 1:24,000 line printer outputs to be obtained. A "modified clustering technique" has proven to be superior to both the "supervised" and "non supervised" (or clustering) techniques that have been used in the past to define training statistics for computer-aided analysis of multispectral scanner data. A combination of three different techniques, including qualitative evaluation, quantitative test field, performance, and acreage comparisons, provide the best overall approach for evaluation of the results obtained by computer-aided analysis of satellite data.

Classification of Landsat satellite data showed that coniferous and deciduous forest cover (as well as other major cover types)

could be identified and mapped with reasonable accuracy (85%) using these techniques.

In spite of the vegetative and topographic complexity of the test site, individual forest types could be classified and mapped with about 70% accuracy.

Acreage estimates of forest cover obtained by computer-aided analysis of satellite data were highly correlated ($r=0,93-0,97$) with acreage estimates obtained by standard photointerpretation techniques using aerial photos.

The application of computer-aided analysis techniques to multi-spectral scanner data from satellites altitudes has been proven feasible. These results indicate a significant potential for mapping and tabulating many of our natural resources over large geographic areas in a quantitative, rapid and cost-effective manner.

JAAKKOLA et al (1978), estimated timber volume in a very inexpensive way by regression analysis achieving correlations of + 0,88 in relation to ground truth maps. A common problem was the estimation of volume in seedling and thinning stands. He found it feasible to determine broad volume and cutting opportunity classes from Landsat data supported by a limited amount of ground measurements.

Similar observations can be seen in the studies of WASTENSON et al (1978); KALENSKY et al (1978); PALA (1978); ZSILINSZKY and PALA (1978); WILLIAMS and HAVER (1976), and CARNEIRO and HILDEBRANDT (1978).

4.2.2. Microdensitometric studies

Concerning the results of a microdensitometric interpretation carried out on Landsat images, HELLER (1976), concluded by the T-test that at a regional level (coniferous forest, deciduous forest, grassland), the differences were highly significant. At a "series level" (mountain bunchgrass, shortgrass, spruce/

fir, ponderosa pine, etc.) results varied. For the three grass, land classes, there were no significant differences in image density estimated from the June imagery. But, there were differences in the August imagery.

Series classifications by optical density levels of the forest units were also variable within and among the two Landsat scenes. Aspen and Ponderosa Pine were discriminated from other forest series classes for both dates on the basis of optical images densities. There was a significant difference ($p = 0,95$) between douglas-fir and spruce/fir on the June imagery, but not on the August imagery. The reason for this difference is not completely understood, but perhaps changes in sun azimuth and and elevation unequally affected the spectral response of the forest types.

Lodgepole pine and spruce/fir were not differentiated at either date. These two kinds of forests normally grow in very dense stands and in similar terrain locations on north and east facing slopes at relatively high elevations. The combined effects of dense canopy cover and mountain shadows at the time the Landsat 1 imagery was obtained resulted in very similar spectral signatures. Corrections for mountain shadows and apparent minor differences in spectral responses relative to the Landsat 1 sensors may improve classification. These ideas need to be investigated since similar classification problems were encountered at the series level using the digital tapes.

KUUSELA and POSO (1972), have also used a microdensitometer for quantitatively evaluating Landsat black and white transparencies. The statistical evaluations were made by regression analysis. However, since very small test-plots (60m. x 60m.) were chosen, the procedure of microdensitometric measurements was time consuming because of the difficulties of placing the plots from aerial photographs (ground truth) to satellite imagery.

5. CHARACTERISTICS OF THE STUDY AREA AND MATERIALS

5.1 Characteristics and Location of the study area

The present study was conducted in the state of Baden-Württemberg located in the south western section of the Federal Republic of Germany. The areas of research were situated within a circle having approximately a 30 kilometer radius from the city of Freiburg (as illustrated in Figure 2), and these areas extended over both flat regions of the Rhine valley as well as mountainous regions of the Black Forest. Altitudes in the research areas ranged from around 200 to 1400 meters, and roughly half the investigations were carried out in the lower elevations and half in the higher.

The areas investigated in the Rhine valley are composed primarily of alluvial soils originating in the Alps and in the mountains of the Black Forest. The climate is typically mild: average annual temperatures vary from 0.6°C in January to 18.6°C in July and average annual rainfall varies from 600 to 900 millimeters. A large number of agricultural fields are found in this area with vineyards located chiefly in the foothills of the Black Forest and in the "Kaiserstuhl" region (an old volcanic formation 25 kilometers north west of Freiburg).

Within this flat Rhine valley area, the dominant forest species are broadleaved with around 50 per cent of the stands younger than 60 years and 50 per cent older. A few small stands 80 to 100 years old can also be found as well as a few stands 120 to 150 years old (e.g., Quercus sp., Fagus silvatica and Ulmus sp.). The floristic composition of these broadleaved forests is relatively varied and the most frequent vegetation species are: Acer campestre, Acer platanoides, Acer pseudo-platanus, Betula verrucosa, Fagus silvatica, Carpinus betulus, Fraxinus excelsior, Populus sp., Quercus sp. and Ulmus sp. For a detailed description of each of these species refer to AMANN (1967).

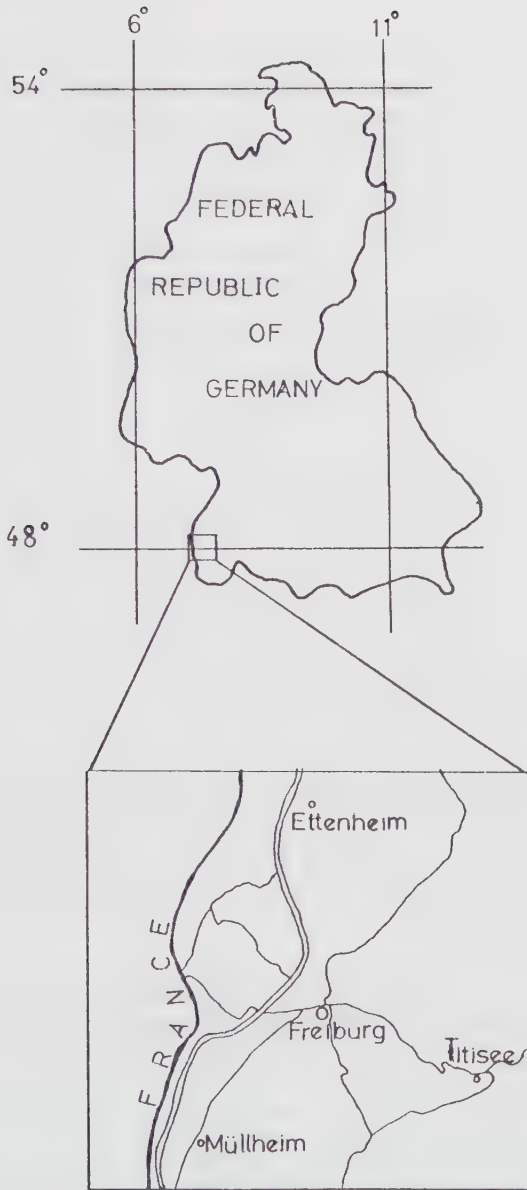


Figure 2. Illustration of the study area

Some evergreen stands such as Pinus silvestris are also found next to the Rhine. These stands are relatively pure with ages ranging from 5 to 60 years. However, they exhibit generally poor development since the soils in which they are growing are very dry and visibly poor in nutrients.

In some other places, as in the souther "Mooswald" Forest, relatively small and young cultivated stands of Pseudotsuga menziesii virk. and Picea abies are also found. They correspond to approximately 5 - 8 per cent of the entire forest.

The Black Forest research area, on the other hand, is formed by gnaissic, paragneissic and clacary soils.

Morphologically, one can differentiate three kinds of relief: a transition zone between the Rhine Valley and the Black Forest foothills, an intermediate area forming a medium high plateau composed of many valleys and medium and high undulated hills, and a very rugged region of terrain alternating with moderate flat terrain. The end of that last area has the general aspect of a high plateau (see figure 4).

The temperatures are lower than in the Rhine Valley area. The coldest month (January) presents an average temperature of $-2,3^{\circ}\text{C}$ and the hottest month (July) $12,8^{\circ}\text{C}$. In the foothills, the average annual rainfall ranges from approximately 850 to 950 mm, in the intermediate area, 1000 to 11000mm. and in the high mountain area up to 2000 mm.

In this area the most common forest species are coniferous, especially Picea abies and Abies alba. Among some others, one can often find Pinus silvestris and some Larix decidua stands.

In the foothills and in the lower parts of the Black Forest, broadleaved species cover about 20 per cent of the forest area (15 per cent Fagus silvatica, 5 per cent Quercus sp. and others). These grow in a mixture with conifers or in small homogeneous stands.

5.2 Material

Basically, black and white Landsat MSS "bulk" images and Computer Compatible Tape (CCT) were used. They correspond to scene number 2199 - 09374 and bands 4, 5, 6 and 7 in scale of approximately 1:200.000 (only the images). Black and white transparencies of the same scene at a scale of 1:800.000 were also used.

These images were taken on August 9, 1975, from an approximate altitude of 915 km. from one point whose nadir-coordinates were 47° 30' N (latitude) and 8° 11' E (longitude).

For the selection of training sets color and color infrared aerial photos of some areas were used, in a scale of 1:11.000. These aerial photographs were taken in 1977 and interpreted through conventional methods with the resulting overlay transferred to a 1:25.000 base-map through an Aerosketchmaster and used for making area estimates by using a polar planimeter.

For a first qualitative method of interpretation of the Landsat images (see chapter 7), only a light table was used.

A second qualitative method of interpretation was carried out through an Additive Color Viewer - I²S - Model 6000 (see chapter 9). By using this viewer, some different color composites were produced from black and white transparencies at a 2.6 times enlarged photographic scale.

For quantitative interpretation of black and white diapositives, the first instrument used was a Joyce and Loeb microdensitometer model 3 CS, which produced densograms of six different test-strips in the four bands, each representing a different forest composition (see chapter 10).

The fourth and last phase, the computer-aided interpretation, was carried out in the German Aerospace Research Center in Oberpfaffenhofen. For this purpose, Landsat CCTs (Computer Compatible Tapes) as well as special computer soft and hard were used (see chapter 11).

Detailed descriptions of the applied methodology for every method will be given in the correspondent phase.

6. PREVIOUS ANALYSIS OF THE TOPOGRAPHIC AND RELIEF EXPOSITION INFLUENCES ON THE SPECTRAL RESPONSES OF FORESTED AREAS

If the photographic process and the quality of the obtained prints and/or diapositives remain constant, then the initial analysis of a forest cover depends directly on the structural and physiological characteristics of the leaves. In the case of any specific forest type, spectral leaf reflectance results from a number of factors such as health condition, age class, stand density, etc., and if these factors also remain constant, then topographical factors come to play an increasingly important spectral role.

Since the present chapter aims only at studying the influence of topography upon the spectral response, topographic maps were used to help keep all other factors as constant as possible. In so doing, only one forest type was chosen: old aged mixed-forest stands with densities ranging from 90 to 100 per cent and with an age class of between 40 and 60 years.

The influence of topography upon the spectral response is conditioned by the different exposition slopes - which is a subject that has only been generally regarded in existing forest typing studies made with the use of satellite data. In the present study, five different relief expositions were selected and by means of a Macbeth densitometer, Model TD-102, ten density readings were carried out for each exposition and for each band. As a result, a total of 200 readings were obtained.

The statistics derived from these readings are given in Table 3.

In an attempt to compare the 20 mean values, the simple t-test was used, the results of which are presented in Table 4.

Concerning practical utilization and additional technical information about the Macbeth densitometer TZSCHUPKE (1974), was consulted.

Table 3. Statistics of density measurements of old aged mixed-forest stands situated on different terrain expositions (each mean was derived from ten measurements)

EXPOSITION (Rugged relief)	4		5		6		7	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
NORTH	0.518	0.0327	0.820	0.0212	0.656	0.0477	0.45	0.0435
SOUTH	0.476	0.0288	0.786	0.0288	0.530	0.0741	0.37	0.0300
WEST	0.692	0.0356	0.878	0.0270	0.642	0.0471	0.436	0.0248
EAST	0.550	0.0158	0.856	0.0109	0.454	0.0662	0.402	0.0248
FLAT terrain	0.348	0.0148	0.606	0.0195	0.484	0.0499	0.314	0.0261

Table 4. Results of the simple t-test carried out for analyzing the differences among five slope expositions (t_9 df.; 0.05 = 2.30)

EXPOSITION	North					South					East					Flat				
	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7
NORTH																				
SOUTH	ns	ns	ns	ns										s	s	s	s	s	s	s
EAST	ns	ns	s	ns	ns	ns	ns	ns									s	s	ns	ns
WEST	s	s	ns	ns	s	s	ns	ns	s	ns	s	ns	s	ns	s	ns	s	s	s	s

s = The value of the calculated t is greater than the tabulated, at 0.05 probability level -
The difference is statistically significant

ns = The difference is not statistically significant

According to the information obtained from the Landsat transparencies themselves, the scene was scanned at a sun elevation of about 50° . For August in the testing area, the south and part of the east expositions received more sunlight in the afternoon. Flat terrain theoretically receives an identical amount of sunlight and consequently reflects an identical amount of radiation.

In order to observe the influence of the aperture size upon the densitometric measurements, three apertures were tested (1, 2 and 3 mm.) - see Figure 3.

Significant statistical differences among the three apertures were not observed (t-test), although the readings made with aperture 3 mm. showed considerable negative influence from small roads (lighter tone values) because of the great measurement area over the terrain (452,39 ha. at a scale of 1:8000,000). This means that it is not so easy to obtain "clean" signatures by using the 3 mm. aperture size und Central European conditions.

As a result, the most suitable aperture for the present area was 1 mm. since this aperture was not statistically different from the 2 mm. Furthermore, the possibility of obtaining "clean" signatures was 9 times greater with the 1 mm. than with the 3 mm. once the area covered by the aperture was reduced to 50,26 ha.

Landsat User's Handbook - USA - (1972), recommends 3 mm. as the smaller aperture size. However, ASHLEY and REA (1975), used apertures as small as 0,4 mm. with great success.

No calibration of the sun elevation was made once image of only one date was used.

By analyzing the results shown in Tables 3 and 4 it can be verified that bands 4 and 5 present similar statistics.

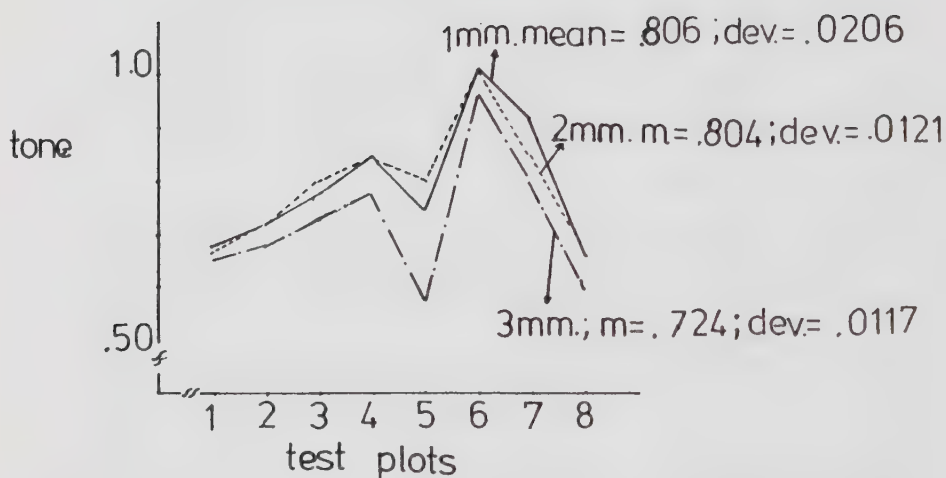


Figure 3. Influence of the aperture size upon densitometric measurements of Landsat forest cover - Presented as example for band 5 and deciduous stands.

The slopes north and south were statistically equal, differing only from west and flat, while the north expositions did not show, as expected, the highest photographic density values. Flat and west expositions, however, differed significantly from the others, as well as the east slope from west and flat. The only deviation occurred in the east slope - band 5 when comparing with west - a difference due most likely to readings made at an exposition with an accentuated per cent of conifers (as was afterwards observed).

The results obtained for bands 6 and 7 were similar (as was the case for bands 4 and 5). However, important differences were reported when comparing the east slope with the others. The scene was probably scanned near noon, once the shadows were practically unobservable in spite of the rugged terrain. This factor must have contributed to the homogeneous distribution of the sun radiation in the five slopes and consequently to the homogeneous spectral reflection registered in every band. This in turn is naturally associated with the spacecraft altitude which must have contributed to the spectral response homogeneity, assuming the same forest cover and band (even if the topographic exposition had changed).

For densitometric studies, the perfect selection, not only of stands in terms of composition and structure, but also of relief expositions, is of fundamental importance for succeeding in obtaining a real spectral table of the stands in study. As has already been seen, two density readings of the same stand may lead to statistically different results if the sun exposition slope is not taken into account.

This is extremely important in choosing test-strips to be used in microdensitometric studies (the theme of chapter 10), as well as in selecting training sets for supervised computer classifications (the theme of the last chapter).

7. QUALITATIVE ANALYSIS OF THE DIFFERENT FOREST TYPES IN THE AREA OF STUDY - BLACK AND WHITE IMAGES

In order to establish the applicability by visual conventional methods of Landsat MSS imagery interpretation for mapping forest stands in the area of study, an analysis in the four bands of the most useful patterns of interpretation was carried out. A Summary of that analysis is illustrated in Table 5.

Since the main goal of the present study was to analyse the forest cover itself, an attempt was made to select the best time of the year and from that choose the scene presenting the best characteristics.

In accordance with HILDEBRANDT (1956, 1973), the best time of the year for forest vegetation cover studies in the test area ranges from May to September for near-infrared images. In addition, as mentioned by SPURR (1960), summer images contain a maximum of information concerning the vegetation, though a little more can usually be learned from double coverage. So, an August scene (late-summer) that perfectly corresponded to all requirements for the study was selected. Another scene of November of the same year was also studied though the additional informative rate was very small. HOFFER et al (1975 b), analyzing orbital Skylab imagery stated that the best time or image for vegetational cover studies was that of August. MARSHALL and MEYER (1978), working under American conditions, also recommended the usage of summer infrared airphotos; finally, HELLER (1976), added that "late spring and late summer are optimum seasons for this kind of mapping in the United States".

Before making the main interpretation, a photoanalysis of the whole area as well as reconnaissance field trips were carried out in order to observe in loco the different stands. A photo-interpretation of existing 1:11,000 color infrared (CIR) airphotos of some areas was also made for establishing the ground truth.

Table 5. Qualitative analysis of the different forest stands in the area of study (Black and White)

Cartographic Level	Forest Cover	Pattern of Interpretation	Bands			
			4	5	6	7
I	Deciduous	tone	dark grey	dark grey	n. obs./l. grey	light grey
		texture	rough	rough	not defined	fine
		relief	flat/mount.	flat/mount.	flat/mount.	flat/mount.
		applicability	****	****	*	**
I	Conifers	tone	dark grey	dark grey	dark grey	medium grey
		texture	rough	rough	rough/medium	medium
		relief	mountain	mountain	mountain	mountain
		applicability	***	***	***	***
II	<u>Pinus silvestris</u>	tone	dark grey	dark grey	medium grey	medium grey
		texture	not defined	not defined	fine	fine
		relief	flat	flat	flat	flat
		applicability	**	**	***	****
II	<u>Picea abies</u>	tone	dark grey	dark grey	dark grey	dark grey
		texture	rough	rough	rough	rough
		relief	mountain	mountain	mountain	mountain
		applicability	***	***	****	****

Boundary delineation: * without applicability *** good applicability
 ** fair applicability **** excellent applicability

Finally, because of the accumulated experiences, it was possible to objectively analyse the different forest stands by using Landsat images. In principle, as already mentioned by HILDEBRANDT (1977), "this approach is very similar to that used in the classified aerial photointerpretation".

Landsat black and white bulk paper prints enlarged to 1:200,000 were prepared and analysed on a light table with a spectral magnifier lens (3.5X) having an additional dispositive for illumination, thus permitting the observation of more details.

Bulk copies larger than the ones produced present clearly accentuated scanning lines and more blurred images that mask the process of interpretation and the perfect boundary delineation of some stands, especially those situated in the foothills. As observed in FAO (1975), "..... beyond that scale interpretation is hampered by the scanning line pattern and the information rate can not be increased." Besides, as noted by MEAD and MEYER (1977), "the smaller scale imagery is more desirable since it forces the user to consider only the broad general patterns of land cover over an entire region and he could not attempt to extract site-specific detailed information from the imagery - a normal tendency - theoretically not well succeeded".

7.1. Band 4

The most used pattern of interpretation for this band was the photographic tone. For the differentiation of flat and mountainous terrain the photographic texture was also used. The tone, however, was sometimes the same for a defined forest cover, both on flat and rugged areas, though this has not contributed to increasing the information rate.

The texture, as expected, was coarser in rugged areas.

The middle-aged P. silvestris stands, although distributed in

significant areal proportions, represented a very small cell of interpretation when compared to the entire satellite scene. In addition, sometimes there were P. silvestris stands surrounded by deciduous stands of the same tone and texture and were misinterpreted as being deciduous. In view of this small area, the results obtained by this method of interpretation must be verified for larger homogeneous P. silvestris stands.

As well stated by McEWEN (1974), it is necessary that certain "objects" be distributed in very significant areal extensions for them to represent their real spectral characteristics in satellites images.

In light of these observations, band 4 was of little visual applicability in delimiting P. silvestris in the area of study. Had these stands been isolated or distributed in greater areal extensions, it would probably have been possible to make better conclusions.

Picea abies could be consistently separated since they represented homogeneous stands. Their homogeneity was greater than 90 per cent, and was distributed over rugged terrain. This conditioned the presence of a typical coarse photographic texture and allowed the definition of the Picea abies stands in this landscape.

By using the photographic tone the boundaries of the deciduous stands could not be perfectly established in the mountainous areas, but only in the flat areas. These boundaries were most distributed on flat areas and this helped in the delineation, since the Landsat imagery was highly applicable for this kind of topography. When stands have a smaller cover density, they are easily characterized in medium grey tones.

In this specific case, since practically all of the mixed-stands were located in the foothills (Rhine Valley - Black Forest), the rough photographic texture was very often used in connection with the "granulated" tone pattern in order to identify that particular forest association.

It can be concluded for this band that forest stands are easily delineated from non-forest areas and that a relatively good separation of the main forest types can be consistently made.

7.2. Band 5

Band 5 is in appearance similar to band 4, though in rugged areas the contrast exhibited between conifers and adjacent areas (corresponding to deciduous or grasslands) is much more prominent than in band 4. In general, the contrasts were more accentuated considering that the photographic process used for producing the paper prints and transparencies was the same.

7.3. Band 6

In view of the similar appearance to band 7, detailed descriptions about the forest stands will be given at band 7.

For deciduous stands, band 6 is of little applicability, especially if the stands are located on flat areas. In mountainous areas they are misinterpreted as grasslands due to the identical light grey tone presented by both vegetation covers.

The great advantage of this band lies in its use for delineating conifers. Physically, the high degree of turgescence ("water retention") found in conifer needles leads to a higher degree of absorption and transmission of infrared radiation. Consequently, the smaller rates of reflexion have a dark grey appearance when seen in a black and white infrared image. In addition, conifers have no spongy mesophyll in the palisade parenchyma, which in deciduous species reflects the infrared radiation, leading to a higher reflection rate and a lighter grey appearance in the infrared imagery. That process is illustrated in Figure 4.

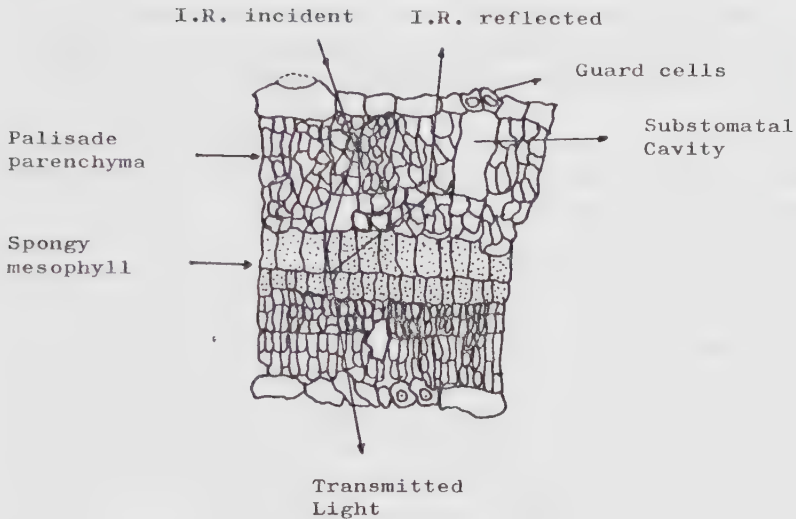


Figure 4. Cross section of a deciduous leaf showing possible pathways for light (modified from GATES, 1970).

7.4. Band 7

The general appearance of this band is similar to band 6. However, for delineation and reconnaissance of deciduous stands it is much more useful than this last band, since deciduous stands, even on flat areas, are perfectly separated and characterized by light grey tones. Small problems, however, can still be observed in the correct delineation of stands lying on flat areas.

The softwoods, for reasons that have been previously seen, are easily delineated. Small Pinus silvestris stands, despite their small areal distribution, could be delineated once they presented a medium grey tone associated with fine photographic texture (that texture was also conditioned by flat relief). Picea abies stands are also very easily recognized in view of

the rough photographic texture and very dark tone.

In general, band 7 presents more accentuated contrasts when compared with band 6, and does not present the continuous light grey background which masks the stand boundaries.

In short, it can be said that a visual interpretation process using black and white paper copies does not succeed in identifying or characterizing all forest species. (Exceptions are Pure Picea abies stands on bands 5 and 7 and Pinus silvestris stands on the same bands. The maximum that can be obtained by using this method is the discrimination of forest areas from non-forest and, at a regional level, a characterization of deciduous forests, conifers and mixed-forests. It is possible to derive more details with more airphotos of "key-areas" or if more field trips, as in the present study, are made. However, the second alternative makes mapping more expensive, especially under tropical forest conditions.

The optimal sequence of interpretation is illustrated in the block-diagram of Figure 5. In this diagram only bands 5 and 7 were used, since they were the most informative ones for forest cover interpretations. Similar observations were also made by HELLER (1973, 1975, 1976), CARNEIRO and SILVA (1976), KLANKAMSORN (1976), NITHACK et al (1975) and ASHLEY and MORIN (1977). Information obtained by the first author, however, (namely that summer images are of little use for forest mapping) lack consistency and do not agree with some results obtained in this study.

The most important deviations as also verified by NITHACK et al (1975), concern the usage of band 5 for basic mapping and the additional information that can be obtained from band 7 (for example, the separation of conifers from deciduous).

The produced diagram must be seen as useful primarily for this area of study. It can also be used for other areas, however, once necessary adaptations must be made. Besides, it considers only those bands whose applicability was highest for forest

cover identification.

The fall imagery could only offer unclear information about some larix sp. stands. In general, additional information could not be obtained that had not already been obtained from the summer scene.

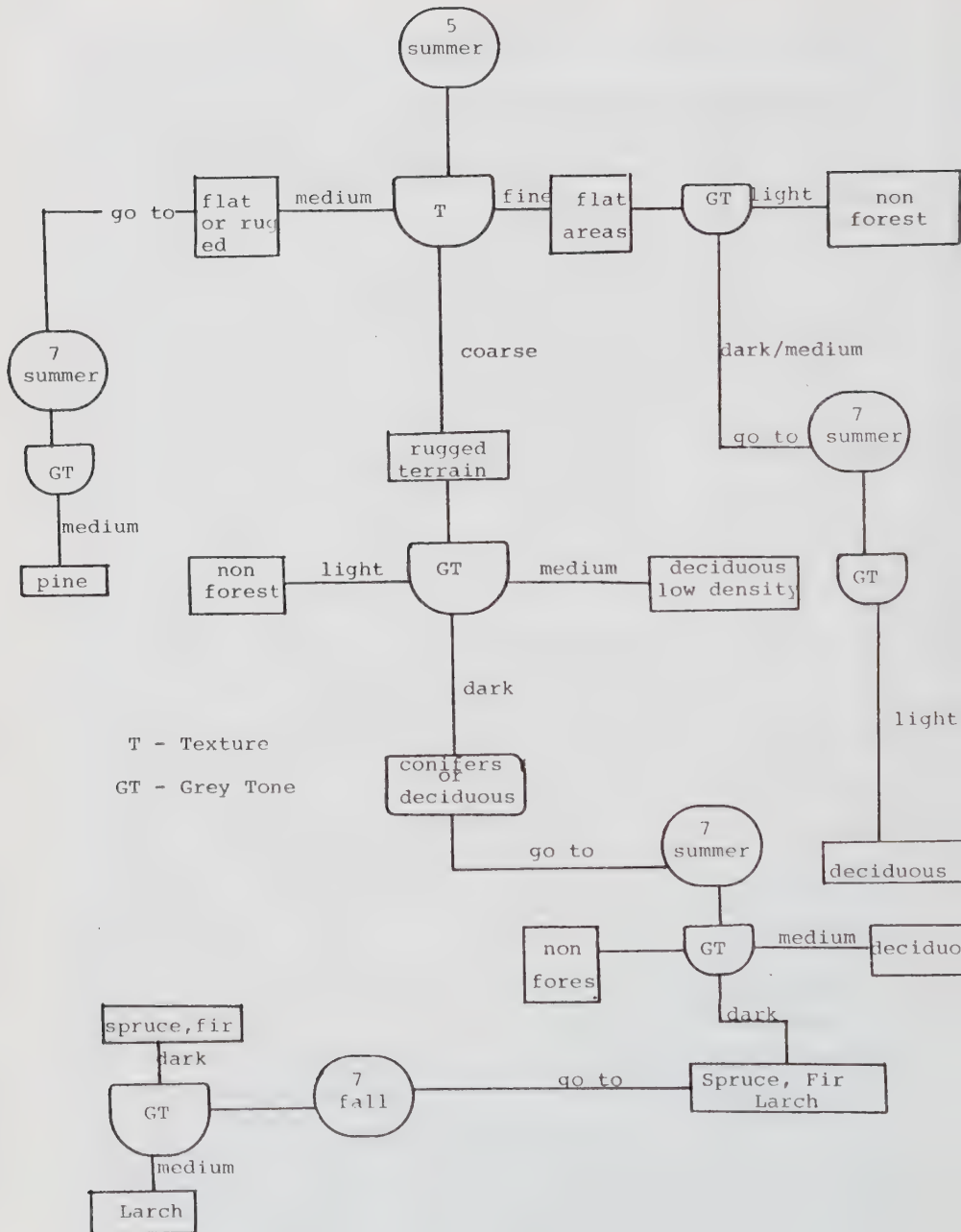


Figure 5. Visual conventional interpretation

8. QUANTITATIVE ANALYSIS OF BLACK AND WHITE LANDSAT IMAGERY

Prior to the present analysis, a preliminary interpretation ("first approach") of the test area was carried out in order to know which parameters in the different bands were the most informative. That analysis was made by interpreting three strips each having a 4 km. x 40 km. area distributed in the valley-mountain direction.

As observed in the qualitative analysis, the most useful band combination was band 4 plus 5 and 7. For the present study, band 5 was preferred for reasons already explained.

Another useful observation is that in areas topographically similar to the one studied, where there exists a flat area (Rhine Valley) composed mainly of deciduous (original vegetation) and a small percentage of planted conifers, plus an intermediate area (foothills) composed of mixed-stands, plus a rugged area (the Black Forest) with a predominance of conifers, there is no need for selecting three relatively small test strips.

The best information can be obtained if one selects a continuous and larger strip representing all of the population. This observation was highly applicable to the area of study.

By applying this method, an attempt was made to determine an area representing the above mentioned pre-requisites. This area is illustrated in Figure 6. Its dimensions range from 14 km. (width) to 47 km. (length) and represent the forest types involved.

This map shows that the ground truth for the studied area originated from color infrared airphotos at a scale of approximately 1:11,000 and forest management maps (1:8000).

Emphasis has been placed upon delineation of interpreted resources, since forest stand delineation from aerial or orbital data is an integral part of a forest inventory (see ELLER and

ULLIMAN, 1974).

The results of the interpretation were transferred to a 1:25.000 base map through an aerosketchmaster. The main problem found in the transference has been referred to the legend. There are many small pure deciduous stands in the middle of coniferous ones (see Figure 10); when the basic vegetation map was reduced to 1:200.000 (Landsat scale), only larger details could be preserved. In short: it was only possible to identify coniferous, deciduous and mixed-forest where "mixed-forest" includes a mixture of small stands and/or a mixture tree by tree. In addition, some specific small middle aged Pinus silvestris stands existing near the Rhine River were also able to be identified.

For the best visualisation of the different stands in the landscape, a topographical profile of the study area was plotted by means of a graphical process, using the contour lines that crossed both sides and the middle of the strip. This profile is illustrated in Figure 7. By analysing this profile it can be concluded that the differences in elevation are accentuated, which contributes to the distribution of different and defined forest types. (see Chapter 5).

The next step was the delineation in the Landsat scene of the corners corresponding to the area of study. This is always a difficult task when the photographic scale is extremely small, since the geometry of the bulk products allows errors ranging from 80 to 200 metres in a point determination on the terrain.

The phases of interpretation are illustrated in Figure 5. These interpretations were carried out on a light table, using rear-projector transparencies (thermofax) and special 3,5 mm. drawing pens. This practice has shown that normal pens and normal transparent papers are not suitable for working with Landsat images since they mask many details. Furthermore, a magnifier lens equipped with a fluorescent lamp was also used, allowing the gain of additional information.

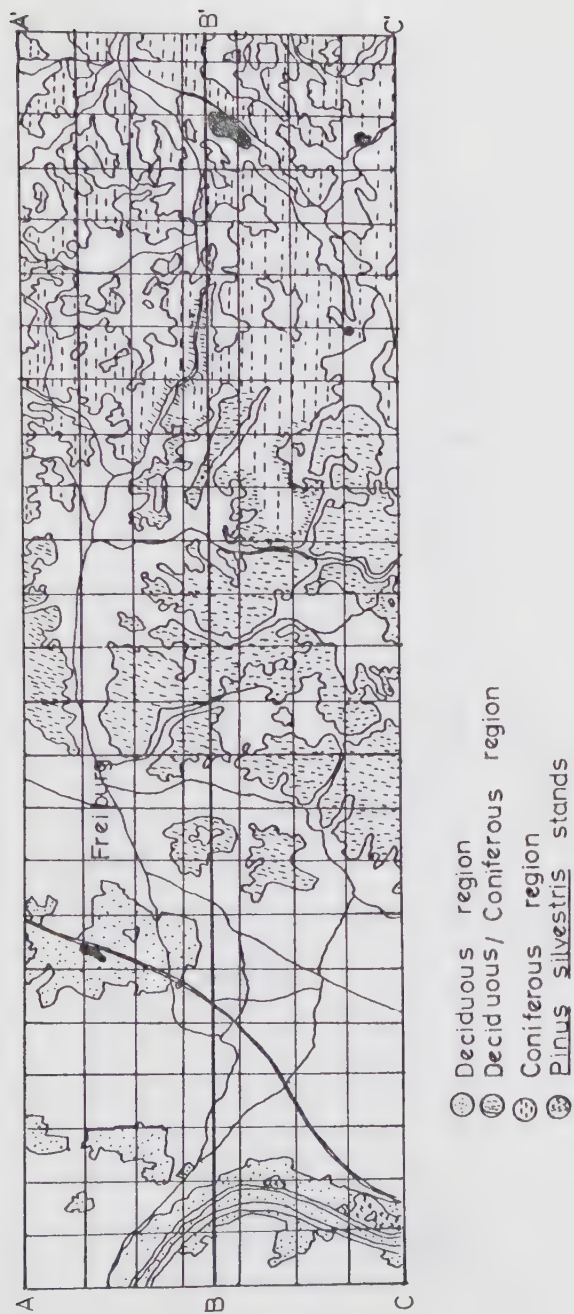


Figure 6. Generalized forest type map (ground truth) of the study area - scale 1 : 200 000

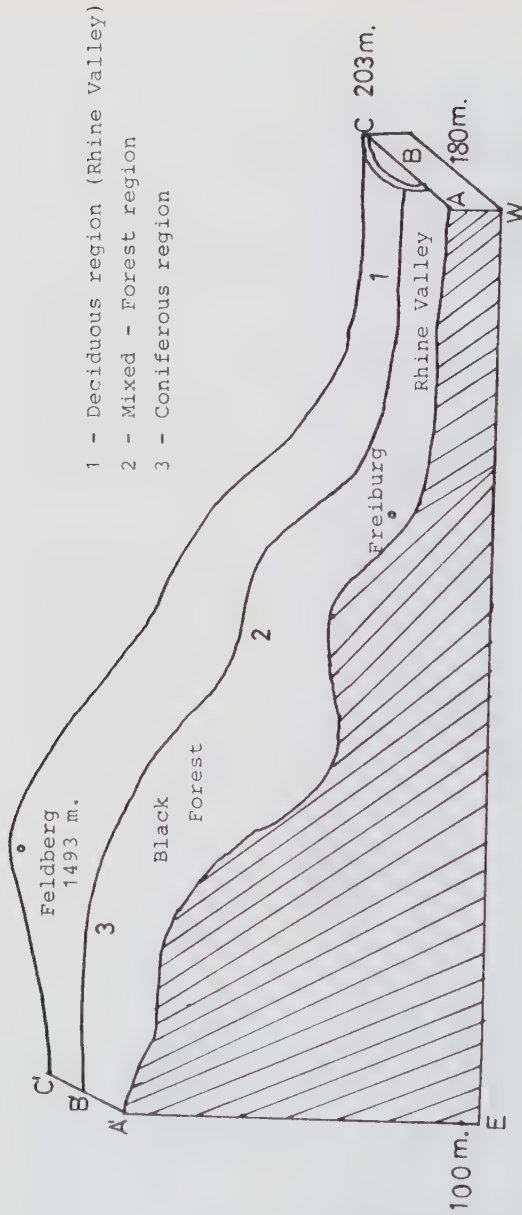


Figure 7. Cross section(profile West - East) of the study area as observed from North to South

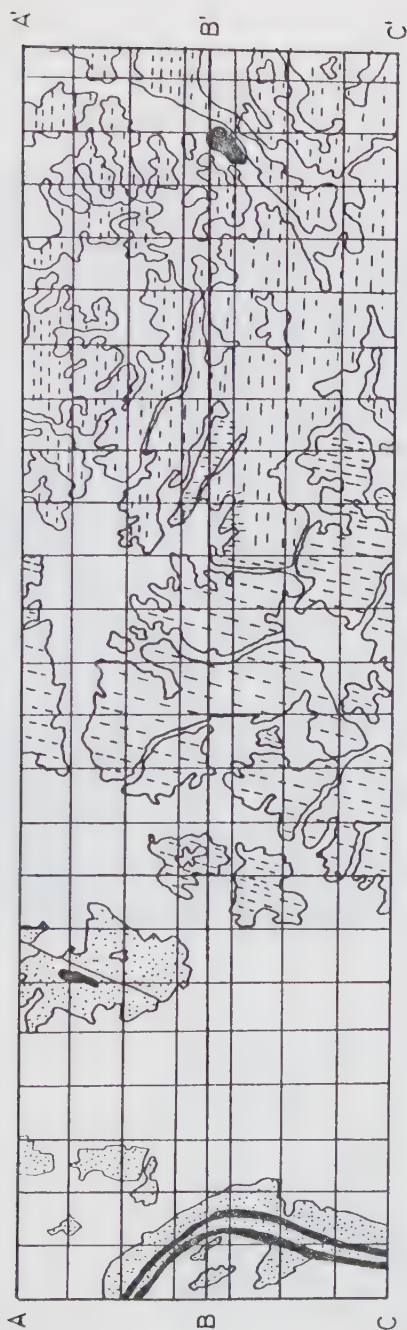


Figure 8. Illustration of the visual interpretation carried out on band 5

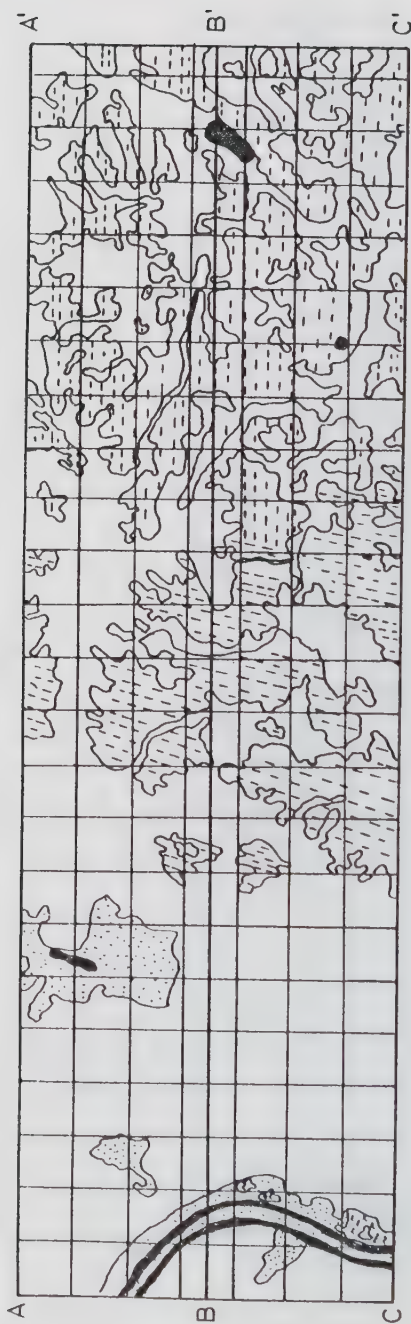


Figure 9. Illustration of the visual interpretation carried out on band 7



Figure 10. Illustration of mixed-forests in the area of study - Infrared black and white airphoto

For calculating the statistics of the test area, the test area was divided into a square grid composed of 161 squares. (see Figure 6), each plot corresponding to a field area of 400 ha. From the total of plots, 142 contained forest land with an area of approximately 56800 ha.

Even so, working with 142 squares for each interpreted overlay (426 squares in total) is a time consuming task, considering that statistically the same precision could be obtained by working with only a smaller number of samples representative of each forest type-component of the population.

Consequently, from the initial population composed of 161 sampling units, a pilot-sampling was made of those units which contained forest vegetation. As a result, it was possible to determine the basic statistics for carrying out a sampling, proportional to the size of the whole population and in accordance with the coverage class. And in every randomly selected plot, better ground truth could be prepared.

For making the "pilot-inventory", 20 per cent of the sampling units composing each class were randomly chosen. Once the basic statistics were determined the question was: how many sampling units are really needed in order to achieve a precision of $E\% = \pm 10$ and in order to sample all three strata with equal precision?

The sampling fraction corresponds, as already seen, to a 1 cm. x 1 cm. square, which in the sampling scale equals an area of 400 ha.

The total number of units was determined by the formula:

$$n = \frac{t^2 \sum_{j=1}^M P_j s_j^2}{(E)^2 + \frac{t^2 \sum_{j=1}^M P_j s_j^2}{N}}$$

where

- n = number of sampling units
 P_j = area proportion of stratum
 M = number of strata
 s_j = standard deviation of stratum j
 N = total number of sampling units (population)
 E = expected sampling error

For application of the formula, table 6 was necessary.

Table 6. Pilot sampling of the forest population for determining the number of units per stratum proportional to the whole population

Class	N_j	P_j	s_j	s_j^2
Coniferous	57	0,4014	3,50	12,243
Mixed-forest	59	0,4155	3,67	13,469
Deciduous	26	0,1831	3,89	15,132
				$\bar{X} = 11,58$ (planimetric reading)
Total	142	1,00		

One takes $t=2$ for a probability level of approximately $p=0,05$ and derives $E = \pm 1,158$ from the mean of the population. It is then,

$$t^2 \sum_{j=1}^M P_j s_j^2 = 53,1255$$

and thence

$$n = \frac{53,1255}{1,158^2 + \frac{53,1255}{142}} = 30,976 \approx 31$$

The sampling units were allocated to the strata according to

$$n_j = P_j n$$

$$\begin{aligned}
 \text{Coniferous} &= 0,4014 \times 31 = 12,440 \approx 12 \\
 \text{Mixed-forest} &= 0,4155 \times 31 = 12,88 \approx 13 \\
 \text{Deciduous} &= 0,1831 \times 31 = 5,67 \approx 6 \\
 \hline
 &\text{Total } 31
 \end{aligned}$$

These values correspond to approximately 20 per cent of each class in the population and were used for estimating the areas of these classes as well as the accuracy performance. They were also used for establishing the equations of simple and multiple regression, representing the linkage between bands 5 and 7 for estimating the areas of the different stands.

ASHLEY and MORIN (1977), working in the USA, found a value of 20 per cent for estimating the accuracy of the mapping.

8.1. Estimation of the Mapping Accuracy Performance

Based upon the results obtained in the last phase, 31 sampling units were randomly allocated. In an attempt to make this task easier, these units were numbered in a sequence of column/lines.

In every sample unit a detailed interpretation (through air-photos) was made.

Following this operation, the areas of the respective sample were measured (in the ground truth map as well as in the interpretation maps of bands 5 and 7) by using a polar planimeter. Each area reading was repeated from 3 to 5 times using the average value.

For evaluation of the acreage accuracy, the number of hectares planimetered in the type map was divided by the equivalent number of correctly interpreted hectares measured in the respective band (see SMELSER and PATTERSON, 1975). When the result of the planimetered interpretation is greater than that obtained in the ground truth, the ratio is an inverse one.

The results and analyses of these measurements are given in tables 7a through 7e.

Table 7a. Acreage estimation for the sampling units of the study area

Column/line location of sample			Coniferous region ha			Mixed-forest region ha			Deciduous ha		
C	C/D	D	ground truth	band 5	band 7	ground truth	band 5	band 7	ground truth	band 5	band 7
15.5	9.5	7.1	240	400	360	300	160	190	240	260	220
16.5	9.6	6.3	280	340	240	40	240	140	200	240	190
17.7	9.7	1.6	280	120	160	260	320	360	100	80	40
17.6	11.1	2.5	300	220	220	280	280	100	240	200	260
17.5	12.1	8.2	300	380	130	200	300	200	160	140	94
17.4	13.1	7.4	100	200	40	160	180	130	120	110	0
18.1	12.2		340	370	360	200	100	270			
18.2	12.6		260	350	300	280	300	260			
23.7	15.7		360	380	320	220	340	260			
23.1	17.7		200	290	300	180	170	90			
21.7	13.7		240	350	220	180	100	200			
20.5	15.3		360	390	320	100	160	60			
	8.5					160	320	90			
12	13	6	3260	3690	2970	2560	2970	2550	1060	1030	804

Table 7b. Class Accuracy Performance

Coniferous	-	Ground truth	X	Band 5	=	113,2 %	Precision	+ 13,2 %
Coniferous	-	Ground truth	X	Band 7	=	91,10 %	"	- 8,9 %
Coniferous	-	Ground truth	X	Bands 5+7	=	102,1 %	"	+ 2,1 %
Conif./dec.	-	Ground truth	X	Band 5	=	116,0 %	"	+ 16,0 %
Conif./dec.	-	Ground truth	X	Band 7	=	99,60 %	"	- 0,4 %
Conif./dec.	-	Ground truth	X	Bands 5+7	=	107,8 %	"	+ 7,8 %
Dediduous	-	Ground truth	X	Band 5	=	97,17 %	"	- 2,8 %
Deciduous	-	Ground truth	X	Band 7	=	75,84 %	"	- 24,2 %
Deciduous	-	Ground truth	X	Bands 5+7	=	86,50 %	"	- 13,50 %

In 31 units of the study area:

band 5	-	Accuracy	=	+5,6 %
band 7	-	Accuracy	=	-8,4 %
bands 5+7	-	Accuracy	=	+1,8 %

Table 7c. Main Statistics

Standard deviation for band 5	=	97,455 ha.
Coefficient of Variation for band 5	=	40,22% (very high)
Standard deviation for band 7	=	109,588 ha.
Coefficient of Variation for band 7	=	55,29% (very high)

Table 7d. Relative Accuracy (among sampling units and per class)

For conifers

Ground truth X Band 5 s	=	13,77 ha. and CV	=	19,19%
Ground truth X Band 7 s	=	19,52 ha. and CV	=	26,52%

For deciduous

Ground truth X Band 5 s	=	13,65 ha. and CV	=	16,59%
Ground truth X Band 7 s	=	37,99 ha. and CV	=	60,36%

For Conifers/Deciduous

Ground truth X Band 5 s	=	23,57 ha. and CV	=	34,94%
Ground truth X Band 7 s	=	21,94 ha. and CV	=	32,08%

Table 7e. Deviations in the Acreage Estimation

- + 5,6% using only band 5
 - 8,4% using only band 7
 - + 1,8% using bands 5 and 7
 - +0,43% using the best band for each strata
 - (Coniferous region bands 5 and 7)
 - (Mixed-forest region band 7)
 - (Deciduous region band 5)
-

The relative accuracy is well illustrated in figures 11, 12 and 13.

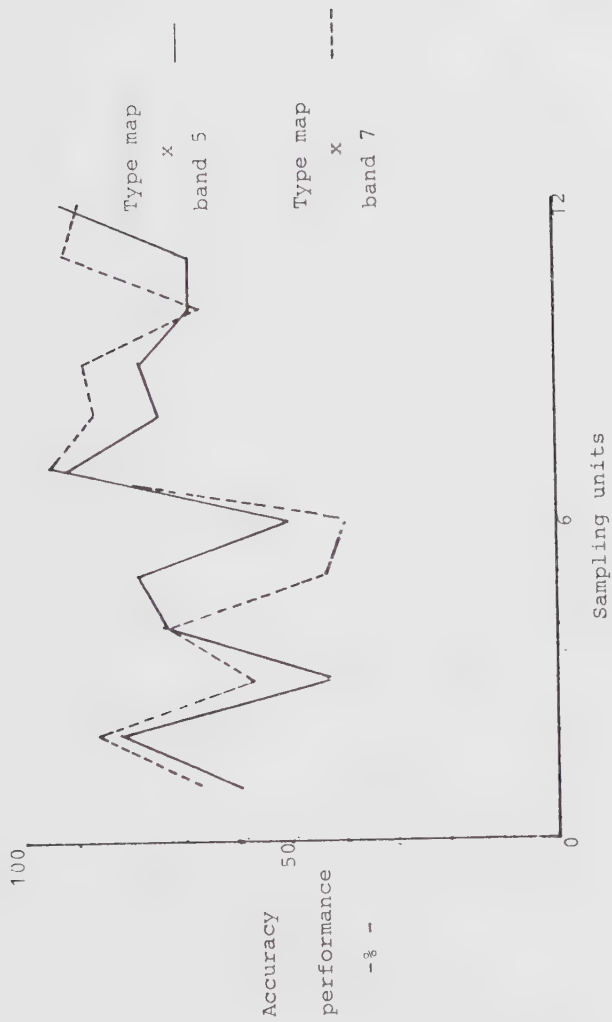


Figure 11 . Illustration of the Landsat visual interpretation accuracy for conifers stands in the study area

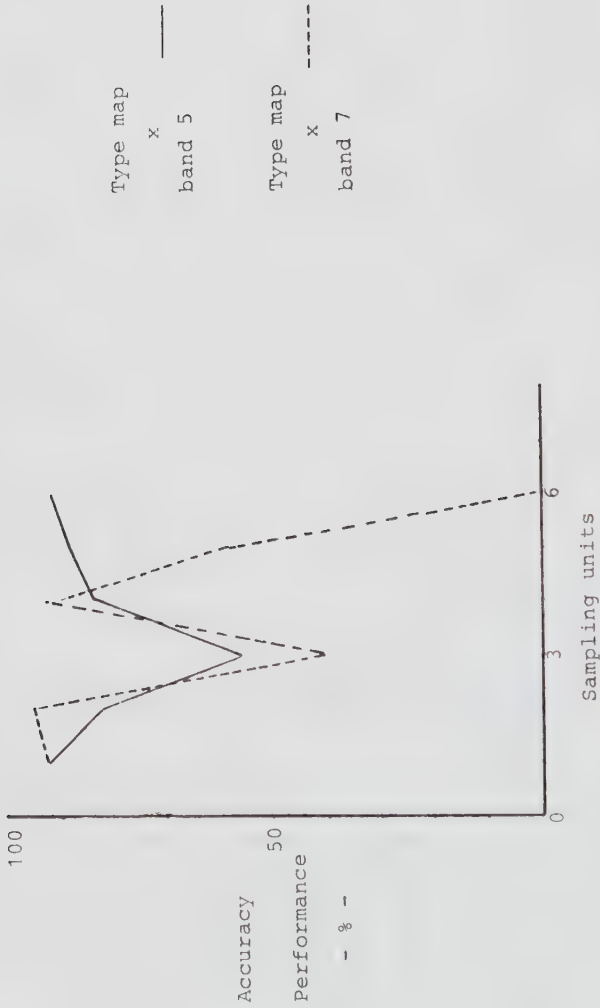


Figure 12. Illustration of the Landsat visual interpretation accuracy for acreage estimation of deciduous stands

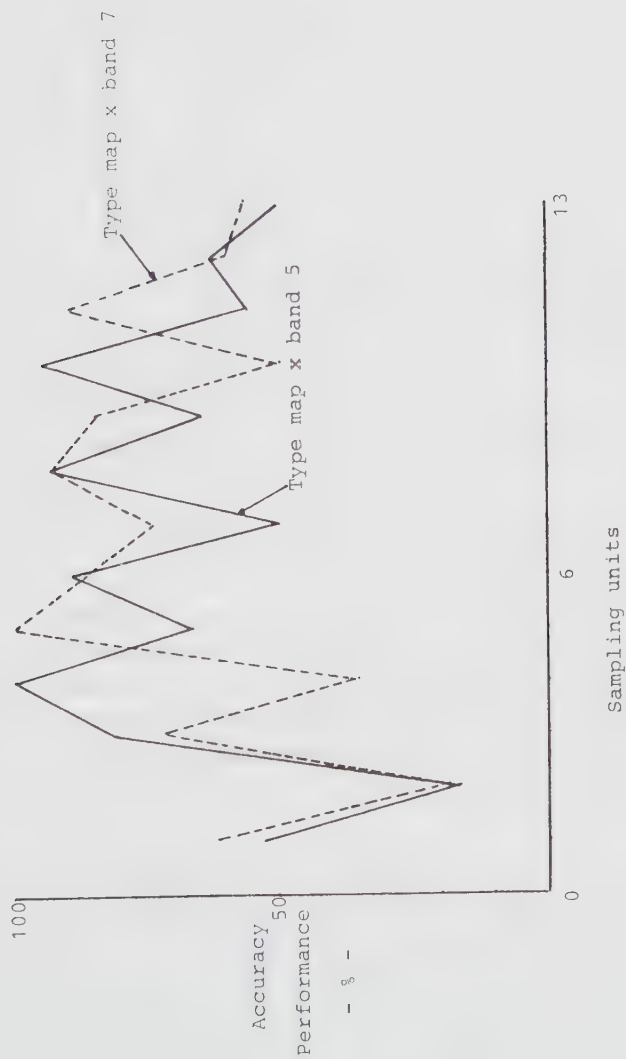


Figure 13. Illustration of the Landsat visual interpretation accuracy for acreage estimation of mixed forests stands

These results refer only to single date images. There are some strong reasons for this. First, temporal studies are highly successful when applied to agricultural studies (see ENGVALL et al 1977), rather than to forestry mapping. For forestry, the value of multi-date coverage is extremely relative. If one works with phenological aspects - see MARTIN, (1973); VINOGRADOV, (1977) - there must have a high importance however, this problem must be investigated on Landsat data in the area of study. Besides, as emphasized by KALENSKY (1974, 1975, 1976), "... the real value of Landsat multi-temporal images for forest mapping is difficult to establish". The same author, working with Automated Procedures, concluded by making use of data from three different dates in a forest mapping in Canada that the increase in precision in relation to identical mapping with a single image was only of 2 per cent, which is highly relative.

Similar observations are also reported by MEAD and MEYER (1977), in the United States.

The high coefficient of variation achieved in band 7 interpretation (Table 7c), must have been caused by the small radiometric fidelity of this band in registering deciduous stands located on flat areas. It was observed that only 75,84 per cent of these stands could be consistently interpreted. This can be observed in Figure 12.

A strong reason for the very high standard deviations obtained in both bands must be related to the geometry of the studied images. These products in the bulk form, present only fair image registration - that is, fair rectification. One can see visually the fair spatial resolution when one compares a dot grid established from a topographic base map with another established from a Landsat bulk image; there can be seen some abrupt differences. These differences were also reported by CARNEIRO (1976). In the test area that problem is observed in band 7 in some deciduous stands. In the used products sometimes that band did not succeed in registering these stands.

Since each sampling unit in the square grid represents an area of 400 ha., the deviations found in both interpretations constitute, practically, one-fourth of this area, which per se is not recommended for operational purposes, except in preliminary mapping operations at reconnaissance levels in areas of poor cartographic base.

For softwoods(coniferous), the best interpretation has been achieved by using both bands 5 and 7. The difference attained by using only one band is relatively high: 13,2% respectively for the whole region and $\frac{8\% - 100\%}{39\%}$ respectively $\frac{6\% - 60\%}{29\%}$ for the 12 test areas located within this region. The plus and minus differences around the average accuracy can be clearly seen and interpreted in Figure 11.

For the interpretation of mountainous mixed-forest stands (coniferous-deciduous with a predominance of the first class), band 7 alone showed a high performance, in light of the highly defined conifer boundaries. When combined with band 5, part of this "clarity" had been a little hampered. The reason for this may lie in the impossibility of separating conifers from deciduous in this band and consequently the incorrect boundary delineation. Compared with the good result for the whole region, the acreage estimation of the single test areas was somewhat confusing. The interpretation of band 7 imagery results in differences of the forest area compared with the ground truth between + 250% and - 64%.

For deciduous, band 5 seems to be the most informative, especially on flat areas, presenting a boundary delineation precision of 97,14 per cent. Band 7 for this purpose is very poor. Besides, the amplitude of the accuracy performance (see Figure 11) was considerably smaller for band 5.

It has been observed that each of these bands is important for a defined delineation. The best solution for the area of study, and the most applicable, is the utilization of both bands. By doing this, an overall mapping performance of 99,57% was

achieved - that is per se very high considering the small information rate obtainable on black and white copies (HARDY and AGAR (1977), obtained in England a precision of 98% in delineating woodland from non-woodland). It is, however, important to mention that this precision refers to a training area. In areas where only little cartographic information and great cover vegetation heterogeneity exist, it probably will not be so high.

By continuing the quantitative analysis, it was attempted by means of simple regression analysis to establish the relation existing between the stands' acreages measured in the type map and those estimated by the average of the same areas measured in both bands 5 and 7. Secondly, with the addition of two other parameters (the photographic tones presented by the same stands in bands 5 and 7), it was attempted by means of a multiple linear regression analysis to compare the influences of the tone upon the acreage estimation as well as the accuracy obtained by both models.

8.2. The Regression Equation Models Studied

$$\text{Model I} - \hat{Y} = a - (X - \bar{x}) b$$

In order to make this study clearer, the two models under investigation were separated. However, in a normal analysis, the simple regression model can be already included in the multiple model.

The basic data used for the analysis are given in Table 8.

For determination of the coefficient of regression b , the following formula was used,

$$b = \frac{\sum XY - \frac{\sum X \cdot \sum Y}{n}}{\sum X^2 - \frac{(\sum X)^2}{n}}$$

and thence,

$$b = \frac{1.677.220 - \frac{6907,16880}{31}}{1.777.189 - \frac{47706649}{31}} = 0,60567$$

considering that $a = \bar{y} - b \bar{x}$, $a = 221,93 - 134,94 = 86,99$

and thence,

$$\hat{y} = 86,99 + 0,60567 x$$

being X, the average acreage value calculated from bands 5 and 7.

However, in order to test the linearity of the coefficient of regression b, as well as the significance of the calculated regression equation, the following test of significance (analysis of variance) was carried out:

Variation	df	sum of squares	mean squares	F
Explained by regression	1	87.405,21	87.405,21	29,98
Unexplained by regression	29	105.678,66	$s_{yx}^2 = 364409$	$s_{yx} = \pm 60,36$
Total	30	193.083,87		

F calculated = 29,98 > F (30;0.05) = 4,18

The regression equation is very significant.

The coefficient of determination among the data is given by,

$$r^2 = \frac{87.405,21}{193.083,87} = 0,4526$$

from this is calculated the coefficient of correlation $r = + 0,67$. The "r" found in tables, to 30 degrees of freedom and 1 per cent precision is + 0,46. This means the regression

lines adjust a very significant portion of the data. In other words, the equation of simple regression calculated for acreage estimation of forest stands in the area of study can be used inside defined limits of confidence. These limits will be calculated after the regression line has been graphically plotted (and after the calculations of the intervals of confidence have been determined) as shown in Figure 14:

To plot the line two points are needed, with $x = 0$ and $\bar{x}$ for $x = 0$

$$\hat{y} = 221,93 + 0,60567(-222,80)$$

$$a = \hat{y} = 86,955$$

With the aid of the standard deviation s_{yx} , the lines which represent the confidence limit about the regression line could be calculated. To plot these straight lines it was again necessary to calculate the coordinates of the two points for each line. As before, the points with the abscissa $x_1 = 0$ and $x_2 = \bar{x}$ were chosen.

For the upper line the following results were obtained:

$$\hat{y}_u = \hat{y} + s_{\hat{y}x} \quad ; \quad \text{for } x_1 = 0 \quad , \quad \hat{y}_u = 147,315$$

$$\text{and for } x_2 = \bar{x} \quad , \quad \hat{y}_u = 282,290$$

and for the lower line:

$$\hat{y}_l = \hat{y} - s_{\hat{y}x} \quad \text{for } x_1 = 0 \quad \hat{y}_l = 26,595$$

$$\text{for } x_2 = \bar{x} \quad = 161,57$$

As already seen, these coordinates were plotted in Figure 13.

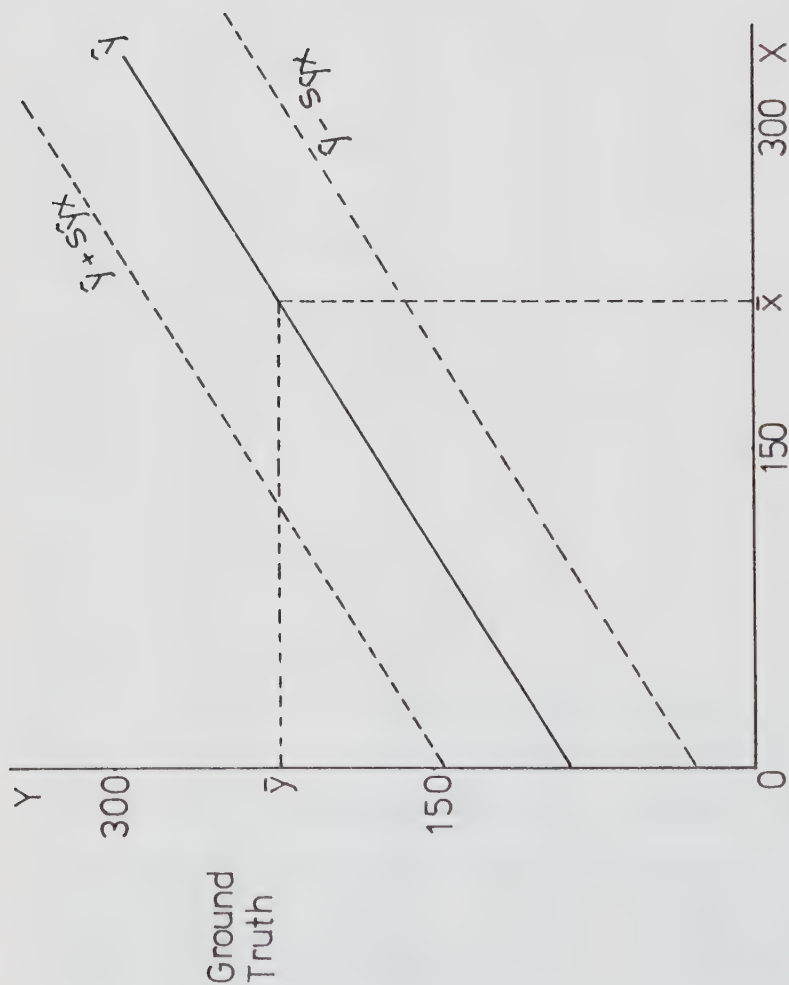
The standard deviation calculated for this regression equation is relatively small ($s_{\hat{y}x} = \pm 60,36$ ha.), suggesting the possibility of utilizing this interpretation method in mapping - at least at a reconnaissance level - even under European conditions.

The standard error a is S_a which is derived by calculating :

$$s_a^2 = \frac{s_{\hat{y}x}^2}{n} = \frac{3644,09}{31} = 117,55 \quad S_a = \pm 10,842 \text{ ha.}$$

Table 8. Data used for calculating the simple regression equation for acreage estimation of forest cover in the area of study

Plot	type map ha	bands 5 + 7	XY	X ²	Y ²
1	240	380	91200	144400	57600
2	280	290	81200	84100	78400
3	280	140	39200	19600	78400
4	300	220	66000	48400	90000
5	300	255	76500	65025	90000
6	100	120	12000	14400	10000
7	340	365	124100	133225	115600
8	260	325	84500	105625	67600
9	360	300	108000	90000	129600
10	200	295	59000	87025	40000
11	240	285	68400	81225	57600
12	360	355	127800	126025	129600
13	300	175	52500	30625	90000
14	40	190	7600	36100	1600
15	260	340	88400	115600	67600
16	280	190	53200	36100	78400
17	200	250	50000	62500	40000
18	160	155	24800	24025	25600
19	200	185	37100	34225	40000
20	280	280	78400	78400	78400
21	220	300	66000	90000	48400
22	180	130	23400	16900	32400
23	180	150	27000	22500	32400
24	100	110	11000	12100	10000
25	160	205	32800	42025	25600
26	240	240	57600	57600	57600
27	200	215	43000	46225	40000
28	100	60	6000	3600	10000
29	240	230	55200	52900	57600
30	160	117	18720	13689	25600
31	120	55	6600	3025	14400
Total	6880	6907	1.677.220	1777189	1720000,
Average	221,93	222,80	$\sum(x_i - \bar{x})^2 = 238264,84$		



Landsat- bands 5 + 7

Figure 14. Graphical representation of the regression line and limits of confidence - Model I

The standard error of $\underline{b}$ is calculated as:

$$s_b^2 = \frac{s_{\hat{y}x}^2}{(x_i - \bar{x})} = \frac{3644,09}{238264,84} = 0,01529; s_b = \pm 0,123 \text{ ha.}$$

If x_i is a fixed value without sampling error, one derives the standard error of the regression estimate corresponding to x_i from,

$$s_{\hat{y}}^2 = s_a^2 + (x_i - \bar{x})^2 \cdot s_b^2$$

$$s_{\hat{y}}^2 = 61,323 \text{ ha.}$$

It is observed that the standard error calculated for the regression line is compatible with the possibilities of this method of interpreting Landsat images. Nevertheless, this standard error can be considered a high one and strengthens the hypothesis of maximum application only until the reconnaissance level of accuracy.

For volume applications see simulations made by KAN, 1978 and JAAKKOLA et al , 1978.

$$\text{Model II} - \hat{Y}_{123} = \bar{y} + b_{123}(x_1 - \bar{x}_1) + b_{213}(x_2 - \bar{x}_2) + b_{312}(x_3 - \bar{x}_3)$$

As previously stated, this model was used to test the possible influences of the photographic tone of different forest stands in the acreage estimation. As has already been observed, the tone plays a special role in satellite visual image interpretation and can be especially observed in deciduous stands situated on flat areas, when interpreted in band 7. Moreover, despite highly successful reports, existing papers do not clarify certain specific relations which must be present among the mentioned variables. Among these papers, KUUSELA and POSO (1972 and 1973) and KINASHI and CHYO (1976), could be mentioned.

An attempt was made to calculate coefficients of regression best fitting the acreage estimations while considering exactly

the great variation observed in the direct estimation from type maps and those estimated from bands 5 and 7.

The photographic density measurements were obtained from black and white transparencies of both bands by means of a Joyce and Loebble microdensitometer, Model 3CS. The microdensograms produced will later be studied as a special topic. The values obtained from these microdensograms were very small, and in an attempt to make them easier to calculate they were multiplied by a constant value of 100.

All of the data used in the present analysis are shown in Table 9). In this table, Y represents the acreage estimation obtained in the forest type map; X_1 represents the average value estimated from bands 5 and 7, X_2 stands for the tone or photographic density value in band 5 and X_3 the corresponding value in band 7.

The first step in the analysis was to verify the existence of regression among the data (X_1 , X_2 and X_3) and the ground truth (Y).

Once verified this relation, one sought to establish the correlation among these variables (quantify the degree of relation) and finally, to verify the existing relations among these data trying to analyse the additive effect of each upon the others.

In order to establish the necessary relations, the following calculations were made: (originated from table 9).

$$\begin{aligned} \sum y_i x_{1i} &= 1.677.120,0 & ; \sum y_i x_{2i} &= 623852,8 & ; \sum x_{3i} y_i &= 420.490,8 \\ \sum x_{1i} x_{2i} &= 629.450,3 & ; \sum x_{1i} x_{3i} &= 421.422,44 & ; \sum x_{2i} x_{3i} &= 163.567,31 \\ \sum (y_i - \bar{y})^2 &= 193.083,9 \\ \sum (x_{1i} - \bar{x}_{1i})^2 &= 238.264,9 & ; \sum (x_{1i} - \bar{x}_{1i})(y_i - \bar{y}) &= 144.211,7 \\ \sum (x_{2i} - \bar{x}_{2i})^2 &= 6266,43 & ; \sum (x_{2i} - \bar{x}_{2i})(y_i - \bar{y}) &= 13.623,45 \end{aligned}$$

$$\sum (x_{3i} - \bar{x}_{3i})^2 = 21.108,17; \sum (x_{3i} - \bar{x}_{3i})(y_i - \bar{y}) = 34960,03$$

$$\sum (x_{1i} - \bar{x}_1)(x_{2i} - \bar{x}_2) = 16.826,14$$

$$\sum (x_{2i} - \bar{x}_2)(x_{3i} - \bar{x}_3) = 9490,61$$

$$\sum (x_{1i} - \bar{x}_1)(x_{3i} - \bar{x}_3) = 34.378,7$$

The estimates of the regressions coefficients are:

$$b_1 = \frac{144.211,7}{238.264,9} = 0,6052$$

$$b_2 = \frac{13.623,45}{6266,43} = 2,1740$$

$$b_3 = \frac{34.960,03}{21.108,17} = 1,6562$$

The sums of squares are calculated as:

$$\sum (y_i - \hat{y}_1)^2 = 193.083,9 - 0,6052 \times 144.211,7 = 105.806,98$$

$$\sum (y_i - \hat{y}_2)^2 = 193.083,9 - 2,1740 \times 13.623,45 = 163.466,52$$

$$\sum (y_i - \hat{y}_3)^2 = 193.083,9 - 1,6562 \times 34.960,03 = 135.183,10$$

The different mean squares were then calculated as shown in the following variation table.

Variation	df	y on X_1		y on X_2	
		SQ	MS	SQ	MS
Explained by Regression	1	87276,92	87276,92	29617,38	-
Unexplained	29	105806,98	3648,51	163466,52	5636,77
Total	30	193083,9		193083,9	
continued.					
		y on X_3			
		SQ	MS		
Explained by regression		57900,8	-	F = 23,92	
Unexplained		135183,10	4661,48	F = 5,25	
Total		193083,9		F = 12,42	

Table 9. Values obtained for studying the multiple regression Model

Y	X ₁	X ₂ [*]	X ₃ [*]
Type map ha	MSS bands 5 + 7	MSS-tone band 5	MSS-tone band 7
240	380	98,86	87,72
280	290	102,92	85,98
280	140	109,30	88,30
300	220	106,40	92,94
300	255	112,20	97,00
100	120	100,60	87,72
340	365	102,92	76,12
260	325	103,50	70,90
360	300	109,30	102,80
200	295	106,98	75,54
240	285	107,56	75,54
360	355	104,66	88,88
300	175	65,68	39,50
40	190	80,18	42,40
260	340	79,60	33,70
280	190	62,60	65,66
200	250	77,86	47,04
160	155	78,44	34,28
200	185	79,60	39,50
280	280	74,96	40,08
220	300	82,50	49,36
180	130	80,76	48,20
180	150	81,34	44,77
100	110	84,82	36,60
160	205	79,60	49,36
240	240	81,34	27,32
200	215	80,76	27,32
100	60	85,40	25,00
240	230	77,86	19,20
160	117	79,60	18,62
120	55	71,48	19,78
total 6880	6907	2749,58	1734,13
mean 221,93	222,80	88,696	56,036
Σ ² 1720000	1777189	250143,5	118450,77

* Values multiplied by 100

The three values are bigger than $4,18_{1,29; 0,05}$

It can be assumed that there exists a regression.

The coefficient of determination r^2 was estimated from the quotient: explained sum of squares divided by total sum of squares.

y on x_1 , $r^2 = 0,452$ and $r = 0,672$ (as already seen on previous section)

y on x_2 , $r^2 = 0,153$ and $r = 0,3916$

y on x_3 , $r^2 = 0,2998$ and $r = 0,5476$

In this case, the independent variables seem to be closely correlated; it can happen that two independent variables determine the same regression. Therefore, we have also investigated the regression between the independent variables x_1 , x_2 and x_3 . It was obtained:

Regression

x_1 on x_2 $b = 2,685$

x_1 on x_3 $b = 1,628$

x_2 on x_3 $b = 0,449$

The absolute values of the regression coefficients could not have indicated the reality of the regression; it was then necessary to carry out the F - test for obtaining the following variation table and F - values.

Variation	df	Regression			
		x_1 on x_2		x_1 on x_3	
		SQ	MS	SQ	MS
Explained by regression	1	45178,18	45178,18	55968,52	55968,52
Unexplained	29	193086,72	6658,16	182295,97	6286,07
Total	30	238264,9		238264,9	

continued overleaf

	Regression		
	x_2 on x_3		
Variation	SQ	MS	F = 6,785
Explained by regression	4261,28	4261,28	F = 8,903
Unexplained	2005,15	69,143	F = 61,629
Total	6266,43		

As the three variables determined significantly a multiple regression one could calculate the three coefficients of regression (b_{123} , b_{213} , b_{312}) by using the following matrix:

$$b_{123} \cdot 238.264,9 + b_{213} \cdot 16.826,14 + b_{312} \cdot 34.378,7 = 144.211,7$$

$$b_{123} \cdot 16.826,14 + b_{213} \cdot 6266,43 + b_{312} \cdot 9490,61 = 13.623,45$$

$$b_{123} \cdot 34.378,7 + b_{213} \cdot 9490,61 + b_{312} \cdot 21.108,17 = 34.960,03$$

238264,9	16826,14	34318,7	144211,7
	6266,43	9490,61	13623,45
		21108,17	34960,03

238264,9	16826,14	34378,7	144211,7
1,0	0,0706	0,1443	0,6052

	5078,50	7063,478	3442,104
	1,0	1,3908	0,67777

		6323,439	9362,994
		1,0	1,48068

$$0,4888 \quad -1,3815 \quad 1,48068$$

$$\hat{Y} = 221,93 + 0,4888(x_1 - 222,80) - 1,3815(x_2 - 88,696) + 1,4807(x_3 - 56,036)$$

$$\hat{Y} = 152,586 + 0,4888 x_1 - 1,3815 x_2 + 1,480 x_3$$

The sum of squares which was explained by the regression was

then calculated as,

$$\sum (y_i - \hat{y}_{123})^2 = \sum (y_i - \bar{y})^2 - (b_{123} \sum (x_{1i} - \bar{x}_1)(y_i - \bar{y}) + b_{213} \sum (x_{2i} - \bar{x}_2)(y_i - \bar{y}) + b_{312} \sum (x_{3i} - \bar{x}_3)(y_i - \bar{y}))$$

$$\sum (y_i - \hat{y}_{123})^2 = 89673,14$$

From this it was obtained:

$$s_{\hat{y}_{x_1 x_2 x_3}}^2 = \frac{89673,14}{27} = 3321,227; \quad s_{\hat{y}_{x_1 x_2 x_3}} = 57,63 \text{ ha.}$$

To estimate the multiple correlation coefficient:

$$R_{123}^2 = \frac{\sum (y_i - \hat{y}_{123})^2}{\sum (y_i - \bar{y})^2} = 0,53557; \quad R_{123} = 0,7318$$

From these results one can see that the standard deviation (57,630 ha.) is only slightly smaller than the one calculated for the simple regression (60,36 ha.). In spite of this, the multiple correlation coefficient ($R_{123} = \pm 0,7318$) is only 6 per cent more accurate than that calculated for the simple regression ($r = + 0,67$).

Undoubtedly, the multiple regression equation is in this case more accurate than the simple one and proves that the photographic tone plays an important role in acreage estimation when using bands 5 and 7. Nevertheless, if one thinks only of practical purposes, the first regression model can be used without great loss in accuracy.

Naturally, if one considers automatic means of interpretation, the standard deviation found in this analysis can perhaps be regarded as a great one (since it represents practically 120 pixels), yet, considering the modest resolution of the bulk paper prints, the results obtained can be regarded as satisfactory ones.

9. MINI-ADDCOL ADDITIVE COLOR VIEWER (I²S, 1971)

The Mini-Addcol Viewer is a compact four channel optical projector. Its function is to facilitate the interpretation of multispectral imagery.

The optical system and controls enable the operator either to project single images or to superimpose two or more spectral images in registration onto a high quality rear projector screen at a fixed magnification. The resultant display is a 23 X 23 cm. image either in a black and white monochrome color, natural color or false color. Photographic reproductions of the displayed imagery of particular interest can be made for permanent records. This can be done by direct photography of the rear projector screen or by utilizing the output reproductions options for the viewer, the print frame and the print console.

9.1. The Optical System

Two of the four channels of the viewer are shown in the optical schematic on Figure 15. The optical path can be traced as follows. Light originating with the DAH lamp indicated by item 1 is collected by the condenser system indicated by items 2 and 3. The condenser system incorporates an IR reflecting glass, thus the majority of the thermal energy never impinges on the film. The visible radiant light then illuminates the film held in the glass plate indicated by item 4. The light proceeding through the film plane progresses through the filter indicated by item 5 through the Schneider lens in item 6, the light is reflected by the mirror and in item 7, the image is projected onto the screen in front of the viewer, designated by item 8.

All four channels work in an identical manner. Registration in X and Y on the screen is accomplished by moving the lens. Registration in the viewers which incorporate image rotation capability is done by rotating the individual film chips.

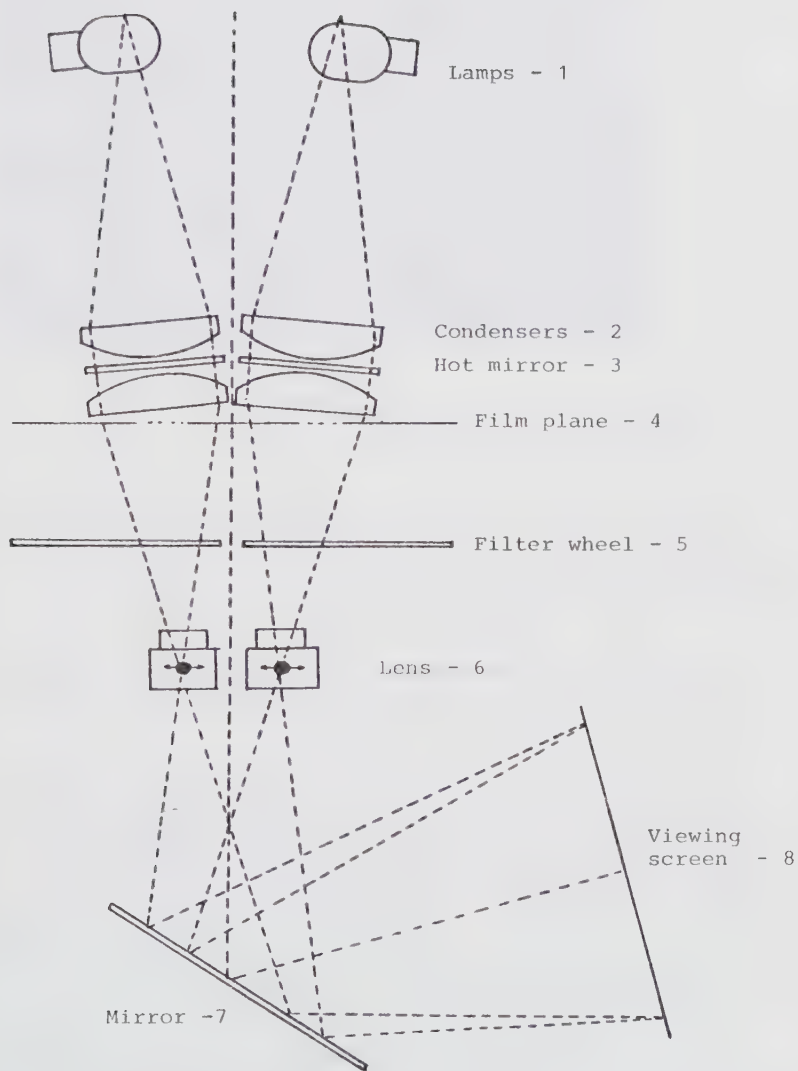


Figure 15. Optical schematic for two of the four channels
of the I^2S Mono Addcol Viewer

The viewer does not have the capability of scale change for magnification variation.

The standard I²S multispectral Mk I camera filter configuration is:

- Band 1 - 47B - Blue
- Band 2 - 57A - Green
- Band 3 - 25 - Red
- Band 4 - 88A - Infrared

When the film is exposed, processed and printed as recommended, natural color images will be formed on the viewer screen by projecting bands 1, 2 and 3 with blue, green and red filter respectively and by balancing illumination intensity in each channel. The "false color infrared effect" results from projecting bands 2, 3 and 4 through blue, green and red filters.

9.2. Qualitative Results Obtained with Landsat-MSS Color Composites

The different color composites produced by the viewer screen presented a scale enlarged 2.6 times to 1:310.000. These different composites originated from black and white transparencies collected on August 9, 1975, and corresponded to the four MSS bands (see Figure 16).

Many combinations were made with the four black and white diapositives. However, considering the goals of the present study, only the main combinations are shown in Table 10.

Table 10. More effective combinations produced in the Additive Color Viewer - Model 6000 with Landsat - MSS images for vegetation cover identification:

Band	Filter	Illumination	Effect
4	blue	6	"false color"
5	green	7,5	
7	red	6	
5	green	8	"false color"
7	red	6	

The color units were classified according to the International System of Color Charts - ISCC - NBS (1968).

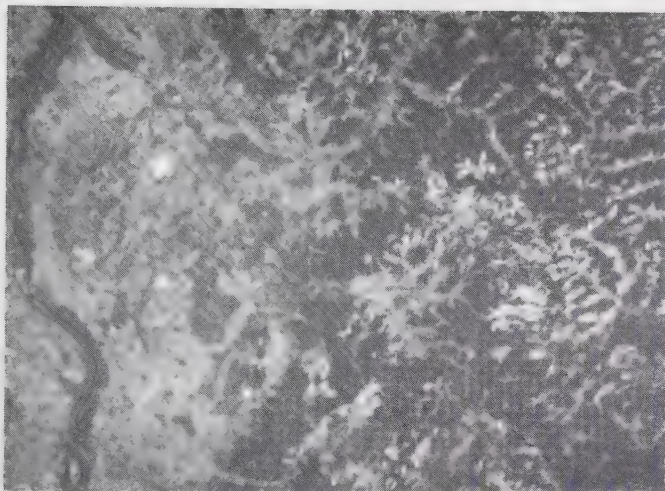


Figure 16. False color composites obtained from bands 4, 5 and 7.

In the first composition (bands 4, 5, 7), mixed-deciduous stands are well characterized in a light red color (approx. 34.v.r 0) when they are located on flat regions. If located on rugged areas they show a darker color (approx. 36 deep r 0).

Middle aged Pinus silvestris stands are always middle-red (40.s.r.Br.) to grey or olive green but a little lighter if mixed with deciduous stands.

Old aged pure Picea abies stands are easily identifiable because they present a typical dark red (16. d. red). However, when mixed with Abies alba their color ranges from the color presented by deciduous stands (mountainous areas) to middle aged pure P. silvestris stands (approx. 38.d.r 0).

Moreover, the first combination presents a visible "blue background", masking certain details especially concerning boundary delineation. This "negative influence" is caused by the presence of the blue filter.

The general aspect of the second "false color" composite (bands 5 and 7) is identical with the first, except the effect background is not as "smooth" and the contrast is undoubtedly more accentuated among the different vegetation types. This makes a better boundary delineation of the different forest types involved possible.

HELLER (1975), made similar observations.

In this study, the usage of bands 5 and 7 is recommended without band 4 because this last band does not offer additional information.

These combinations are somewhat different from the ones obtained by van ES in India (1974, 1975). This is because van ES used band 5 with a red filter and band 7 with a green filter together with band 5 without filter plus band 7 with a red filter (Multidate).

It is important to observe that some vegetation cover details were not observed in the photoanalysis since they were very small in relation to the image resolution. Some mixed reflections are recorded (also NITHACK et al 1975). Moreover, after the first interpretation of existing color and infrared color airphotos of some areas, these "doubts" were taken and the results extrapolated to other areas with similar problems.

The details in the satellite composites were more visible every time since information from forest management maps and field work was obtained in such a way that some mixed-evergreen stands (Picea abies and Pseudotsuga menziesii) found in southern Mooswald Forest (Freiburg north-west) were clearly visible and interpreted because of their dark red tone in the middle of a bright red, corresponding to deciduous stands. This was in spite of their small areas - 5 to 8 % of the whole forest. These small evergreen stands are clearly lighter than those situated over mountainous areas, probably because of their exposition slope.

After the first aerial photointerpretations of these small "problem areas" the entire Landsat scene could be correctly visually interpreted. Some stands were very small and could not be represented in the general map legend.

Figure 17 shows through a diagram the steps for correctly identifying the forest types involved in this study only by using color tones, considering that the photographic texture is very "smooth" in all types.

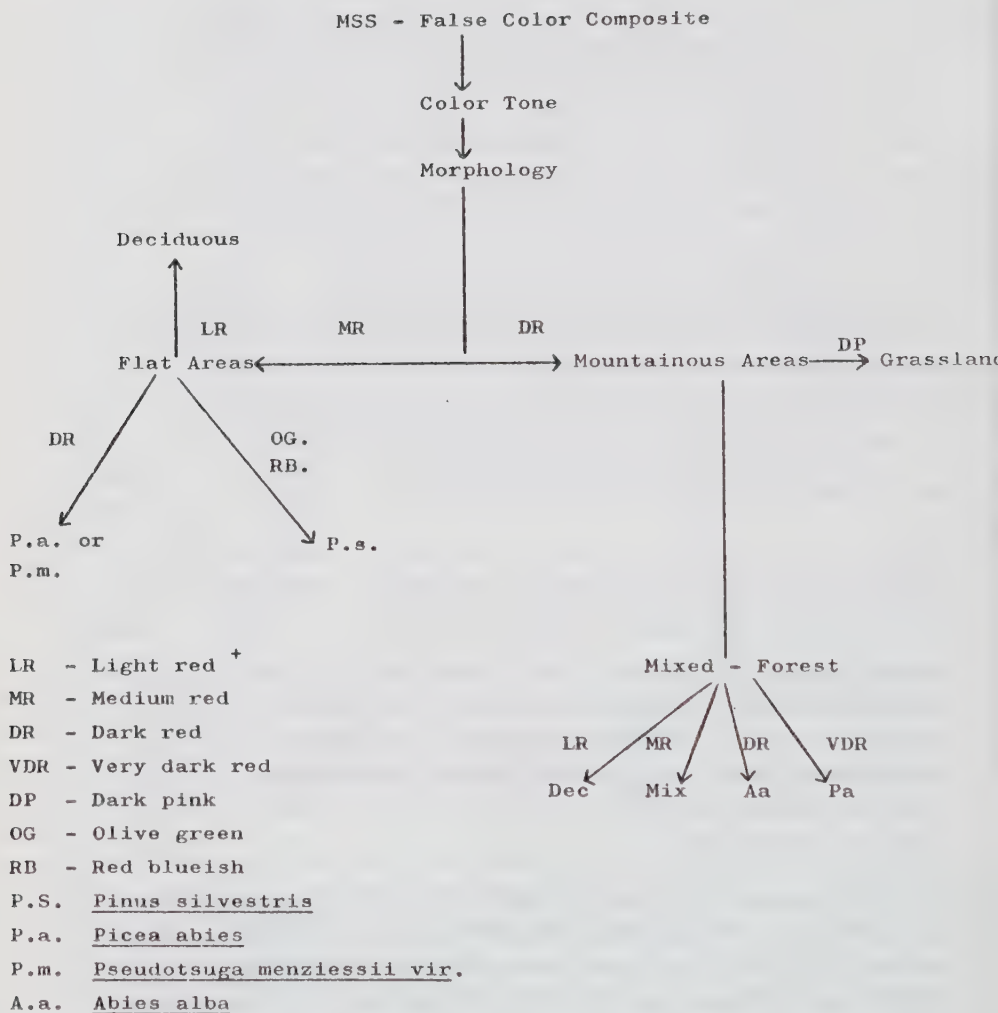
A similar false color effect was also produced by replacing band 5 with band 4. However, no additional information was obtained. On the contrary, this replacement resulted in a bad quality composition with a very poor color contrast.

Band 6 did not offer additional forestry information that had not already been obtained with band 7.

Forest exploitations were relatively easy to identify and this information can be important for monitoring programmes up to a semi-detailed level.

Another scene of the same area from October 9, 1972 (false color) presented by HEUSELER (1973) was also studied. The print quality was not as good but sufficient to observe that no new information could be acquired. The only difference was that this scene highlighted more the spectral differences between conifers and deciduous.

The Color Additive Viewer proved to be a very helpful instrument for analyzing Landsat transparencies. However, since it was not originally designed to work with Landsat products some clear disadvantages can be seen. We can only work multispectrally with little enlarged copies since the viewer was originally made to operate with 7 x 7 cm. copies. For Landsat that still represents a very small scale. Besides, we need to arrange the copies in an extra transparency with X,Y coordinates in order to superimpose the images for multispectral studies and that is time consuming.



⁺Color patterns classified according to the Int. System of Color Charts
- NBS

Figure 17. Diagram of the results obtained in the visual interpretation carried out in the area of study (Color Additive Viewer).

9.3. Quantitative Evaluation of Landsat Color Composites

For making quantitative evaluations some stands were chosen. These evaluations are shown in Table 11. It was necessary to acquire the necessary ground information about these stands in order to make accurate statistical determinations.

The whole Landsat color composite was thoroughly examined and some stands representative of the whole area were chosen as test areas.

These stands were interpreted through color infrared airphotos and their areas were measured with an OTT polar planimeter. Unfortunately, many details of the ground truth map were lost after their reduction to a 1:50,000 scale. This again shows that scales smaller than 1:50,000 do not meet the information requirements of high intensive forest management systems.

The statistical relations between the areal estimates obtained by both methods were determined by using the analysis of correlation.

Table 11. Acreage estimation of forest types in the area of study (on training area)

Cover Class	Ground truth-ha.	%	Landsat ha.	%	Error %
Deciduous	1456,0	20,78	1430,0	18,64	- 1,8
Mixed-forest	2926,4	41,77	3568,29	46,48	+21,9
<u>Picea abies</u>	1876,8	26,79	1938,0	25,25	+ 3,3
<u>Pinus silvestris</u>	746,0	10,66	739,0	9,63	- 0,9
Total	7005,2	100,0	7675,29	100,0	+ 9,59

Based on these determinations, a linear regression equation was calculated in an attempt to estimate forest acreage.

The calculated parameters were:

$$a = + 307,69 \quad \text{and} \quad b = + 0,752343$$

$$\bar{x} = 1751,30 \text{ ha.} \quad \text{and} \quad \bar{y} = 1918,82 \text{ ha.}$$

The equation,

$$\hat{y} = + 307,69 + 0,752343x$$

where x is the Landsat estimated forest resource.

The coefficient of correlation calculated for that regression was $r = 0,9928$ (very significant at 0.05 probability level).

It is clearly seen by the results that a high overall accuracy of 90,41% was obtained.

The highest difference in areal estimates was obtained in the mixed-forest stands (+ 21,9%) situated in the foothills. This was probably caused by the abrupt topographic change between the flat areas and the mountainous areas, as well as by the presence of many vineyards in the boundary area. These were probably the most important reasons for the difference obtained from the satellite interpretation.

The problem of field prediction regression equations has begun to be enthusiastically researched as shown by the works of LUND (1974), LUND and KNIESEL (1975), and HYDE (1977). Photo characteristics serve always as independent variables and corresponding field data as the dependent variables.

A constant in these studies is the creation of special data files that may be required for each new problem. Comparisons between data files generated by manual techniques from various data sources, including photo interpretation, and the satellite data are almost identical, and consequently more credibility is given to the satellite data. Assurance of dependable data is necessary if further applications of these data are to follow, especially in large area forestry inventories.

For the present study area, however, the calculated equation must be looked at only for general purposes - that is, for reconnaissance estimates when the dispersions in data collection are relatively high (see mixed-forest estimates) and when the degrees of freedom are low.

Nevertheless, in areas of large homogeneous stands where a

good basic knowledge of the structure and nature of the investigated cover is known, these regressions can be of high value when using Landsat data.

10. MICRODENSITOMETER

In order to calculate the optical density variations (also known as tone variations) of the different forest types in six test-strips, a double-beam recording microdensitometer - model 3CS from Joyce Loebble C. Ltd. was used.

10.1. Principle of Work (AKCA, 1970, 1971; Joyce Loeb1)

The measuring method of the instrument is based on a double-beam system, in which the light from a simple source is led along two paths. In the first path, lies the measuring object; in the second, stands an optically gauged grey scale or wedge. At the exit of both paths, the light intensity of the beam bundle is dependent on the absorption in the individual media. A photomultiplier finally receives both beam bundles, which, with the help of a synchronised motor, are allowed to pass through interchangeably. If the two beam bundles have different intensities, then the photomultiplier produces a differentiating signal, causing a servo-motor to move an optical attenuator (the gauged optical grey scale) in such a way that the intensity difference of both beam bundles at the exit of both optical paths is zero.

The position of the attenuator, whose movement is conveyed on a recorder, registers the optical density on the respective place on the scanning spot. The entire system is illustrated in Figure 18.

10.2. Description of the Instrument

The microdensitometer is basically composed of the following parts:

- 1 - An optical device on which the density reading depends.

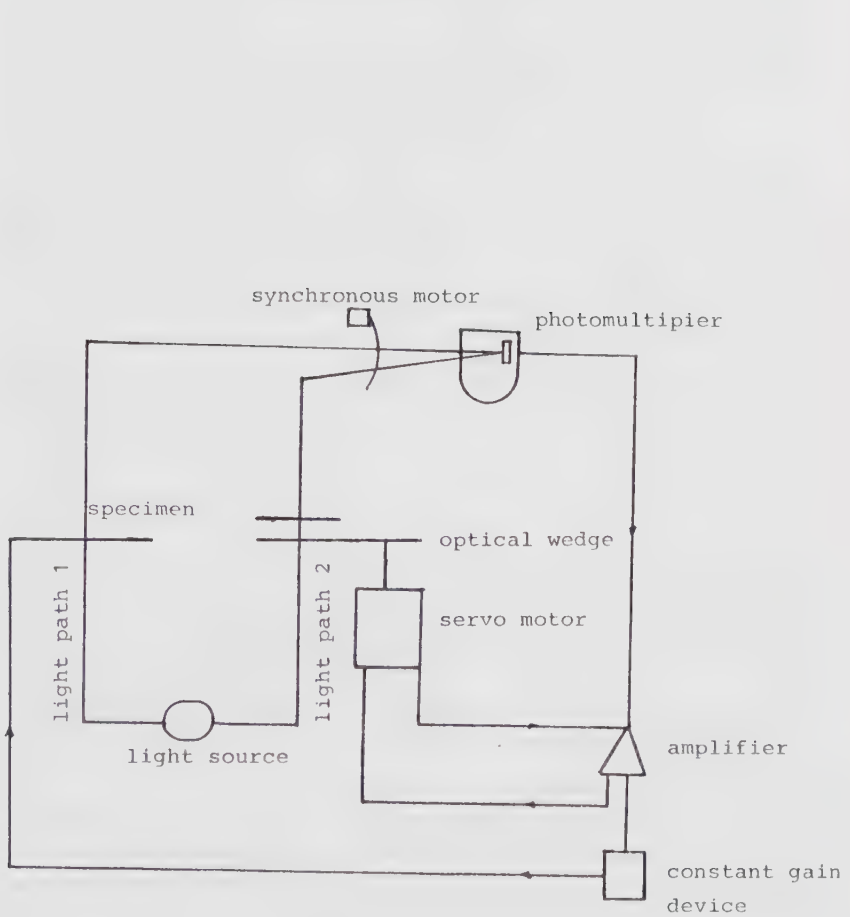


Figure 18. Schematic representation of the microdensitometer model 3 CS from Joyce - Loeb

- 2 - A wedge differentiating system which automatically maintains equal absorbtion (light intensity) in both optical paths.
- 3 - An electromagnetic propulsion system which moves the measuring and the registering tables. Both tables are moved by another servosystem at an interchangeable speed proportional to the density variations. If the density variation is small, the propulsion speed is maximal and vice-versa. The mechanical construction relation between both tables enables a comparison of the exact measurement extension of the measured object's details.
- 4 - A focus adjusting mechanism which aids in both the introduction and observation of the measured object.

10.3. Way of Working

The measured object is firmly placed on a moving rectangular table (measuring table). The object is then correctly attached in the zone and direction of the density scanning variation and finally, the registering paper (milemeter paper) is tightly fixed, by means of special grips, on the registering table which itself is linked by mechanical construction with the measuring table.

The instrument offers the possibility of producing already enlarged densograms. The enlargement factors range from 1 to 50 (i.e., 1:1, 1:2, 1:5, 1:7,5, 1:10, 1:20 and 1:50), and as a result, the absciss scale factor of the analyzed zone can be regulated according to the user's need. The pen, which is mechanically linked to the grey wedge, draws the optical density variations on the registering paper.

10.4. Ground Truth and Laboratory Data Acquisition

Both ground truth and laboratory data were acquired essentially

at the same time. Six experimental test-strips were chosen, both in flat and rugged areas, with each test-strip representing a different forest cover. Every stand having at least 50 per cent of a single forest type was considered pure. For mixed-stands, the forest type was written first whose percentage in the mixture was more significant.

At the start, the different strips were chosen only by using Landsat black and white transparencies of the four MSS bands. Later, the choices could be improved by using color and false color aerial photos of some areas and forest maps of others. Finally, the different stands were visited. For detailed information about some of these forests, data were obtained from management maps belonging to the Forest Service.

The six selected test-strips were:

- Strip 1: old pure Picea abies stands in mountainous areas (the Black Forest);
- Strip 2: old aged mixed-coniferous stands in mountainous areas, composed basically of Picea abies and Abies alba and also having a very small percent of Pinus silvestris;
- Strip 3: old aged mixed-deciduous stands situated in the Rhine Valley, composed mainly of Fraxinus excelsior, Quercus sp., Alnus sp., Fagus silvatica, Ulmus sp., Populus tremula, Populus sp., Acer spp. and pure middle aged Pinus silvestris.
- Strip 4: old aged mixed-forest stands situated in rugged areas, with at least 50 per cent deciduous stands with a floristic composition similar to strip 3 and 50 per cent P. abies, Abies alba and Pseudotsuga menziesii viridis.
- Strip 5: middle aged mixed-deciduous together with middle aged Pinus silvestris situated on the edges of the Rhine Valley.

Strip 6: middle aged mixed-deciduous stands located in the Rhine Valley with the same forest species found in test-strip 3. Here, some old Quercus sp., Fagus sp., Ulmus sp., and Fraxinus sp. exemplars are also found. Approximately 8 per cent of the entire floristic composition is composed of middle aged mixed-coniferous stands.

10.5. Evaluation of Microdensograms

Twenty-four densograms were produced corresponding to the selected different forest types and these densograms are presented in Figures 19 through 42.

On the presented densograms, darker tones correspond to greater tone values. For the determination of the average density values, every densogram was divided into 51 parts and in each part a reading was made. The total value was again divided by 51 and an average density value was obtained. For conducting the statistical analysis of these different density values, the simple multiple t-test was chosen. (HELLER (1975) also used this test successfully for investigating similar problems).

In this study, successful identifications were made at a 0.01 probability level.

The following formula was used for carrying out the t-test:

$$t = \frac{X_1 - X_2}{\sqrt{\frac{s_1^2 + s_2^2}{N}}}$$

where:

X_1 = Average value of the population 1

X_2 = Average value of the population 2

s_1^2 = Variance of the population 1

s_2^2 = Variance of the population 2

N = Number of components in the population 1 and 2

10.6. Photographic Texture Measurement of Different Forest Covers by Means of the Microdensitometer

After detailed study and complementary fieldwork of the different forest types involved, all the forest types were marked on four transparencies corresponding to the four Landsat bands. As a result, the densograms for every forest cover were produced.

For the present study, it was observed that the the optimal effective scanning area (scanning width x scanning height) was 20×20 microns approximately 256 m^2 in the terrain. In the case of satellite imagery especially, smaller areas were extremely difficult to measure due to the coarse graininess presented by the obtained Landsat photographic enlargements. Also, in larger areas, satellite imagery omitted many details. See also AKÇA (1970) and DOVERSPIKE et al (1965), for detailed discussion about this point.

The enlargement factor chosen was 50 (the maximal instrument factor). One of the reasons for this choice was the photographic scale used (approx. 1:800,000 - see below- which is very small for clearly observing certain stand boundaries. By using the chosen factor, every detail was enlarged 50 times in the X - direction. The register in the Y - direction (contrast) depends on the gray scale. In this case, a grey scale with units ranging from 0 to 4.00 was used, which presented no difficulties concerning the linearity of the instrument.

For selecting the most adequate photographic scale, three scales were studied: 1:1,600,000, 1:800,000 and 1:400,000. The first was extremely small and made it very difficult to separate forest stands that could be clearly seen on forest management maps. In the case of the 1:400,000 photographic scale, the original scanning lines were so prominent that the resulting densograms were more a result of these lines than of the forest stands. The only and best solution was to choose the approximately 1:800,000 photographic scale, though theoretically the combination of scale 1:400,000 with scanning area $10\mu \times 10\mu$

would produce similar results to 1:800,000 and $20\mu \times 20\mu$. In the practical work, some difficulties were found caused by "image quality".

Finally, bands 4 and 6 as well as bands 5 and 7 were selected in order to conduct a cluster analysis of the different density values obtained from the different strips. As a result, it was possible to observe the successes and problems in separating the forest types involved.

10.7. Statistical Analysis of the Different Test-Strips in Every Landsat - MSS Band

10.7.1. Band 4

The statistical evaluations for this band are illustrated in Table 12. This band, as well as the three others, shows in rugged terrain that the results seem to have suffered some negative influence from the relief itself - shadows, small roads and other small non-forest lands. In fact, if a "pure" density value of, for example, old aged mixed-coniferous stands is obtained, the value will surely be greater than 0.6014. In this study, however, the photographic scale was so small than these influences were not able to be controlled.

Another visible influence was provided by the scanning lines. The more the original scale (1:3.369,000) is enlarged, the more a negative influence is observed. It can happen that only these lines are registered if one uses, for instance, a transparency enlarged by 10 times. Consequently, it is advisable to use a maximum scale enlarged by only 4 to 5 times when using these diapositives in this instrument.

As observed in Table 12, it is possible to separate pure Picea abies stands from other forest covers without difficulty. Visually this separation is almost impossible to make. The same happens with P. abies/coniferous(old aged mixed-coniferous stands).

It was not possible to separate middle-aged deciduous stands from old deciduous stands. Perhaps, the per cent of deciduous stands in the second unit made the separation impossible. In addition, it was also impossible to separate mixed-deciduous/P. silvestris stands from old aged mixed-deciduous stands for similar reasons.

It is important to observe that in the densogram corresponding to strip 3, it can be clearly seen that the presence of a small middle-aged coniferous stand together with some shadows has affected the resulting average density value of this strip.

Densogram 4 reveals the effect of rugged relief, which has probably affected the total density value for that strip.

Also, the densogram corresponding to strip 6 shows light influence of a small barren land, though the total density value was not seriously affected.

10.7.2. Band 5

Test-strip 2, as seen in the corresponding densogram, was strongly affected by the relief. This is statistically proved by the high coefficient of variation presented by the density values (as illustrated in Table 19). In spite of this, it is very likely that the total density value did not diverge a great deal from the real one. Similar influence can also be seen in test-strip 4. Moreover, in this band the separation of middle-aged mixed deciduous stands from old aged coniferous stands was not possible. The reason for this was already given.

It was not possible to separate Picea abies/old aged mixed coniferous stands from mixed-forest. Both stands were located in rugged areas and had high percent of conifers in the mixture which resulted in similar spectral and textural characteristics.

Another problem was found in the Picea abies/old aged mixed coniferous stands and the old aged mixed-deciduous stands. This problem is quite difficult to explain. Possibly, the

influence of small country roads, barren lands and very small deciduous stands occurring in the first unit are the reasons for the statistical similarity. As was already discussed, these influences are very difficult to control in view of the small photographic scale.

10.7.3. Band 6

As seen in Table 12, the separation of mixed-deciduous/P. silvestris stands from mixed-deciduous (middle and old age stands) was not possible because of the 0.01 probability level. The spectral characteristics of both forest covers are very similar at the accuracy level.

The statistical difference between both middle and old aged mixed-deciduous stands was also not significant.

By observing the densogram corresponding to strip 6, some "peak values" are easily visible. These values correspond to a middle-aged Picea abies/Pseudotsuga menziesii stand. Furthermore, the densogram is useful for showing the accentuated difference between coniferous and deciduous stands, due naturally to their different spectral characteristics. However, these high density values greatly affected the coefficient of variation obtained from the average strip density (as shown in Table 19).

The high coefficient of variation obtained for strip 5 was due to the extremely light tones presented by mixed-deciduous stands and dark tones presented by Pinus silvestris stands.

10.7.4. Band 7

As shown in Table 12, in band 7 as in band 5, it was not possible to differentiate Picea abies/mixed coniferous from mixed-forest stands.

Mixed-deciduous/P. silvestris stands were statistically dif-

ferent from middle-aged mixed-deciduous, though they were not different from old aged mixed-deciduous stands.

Also, the negative relief influence here was very clear, chiefly in strips 2 and 5, as shown by their coefficient of variation, illustrated in Table 19.

10.8. Statistical Comparisons Among Landsat - MSS Bands

10.8.1. Strip 1

According to the obtained results, all four bands can be used to identify pure *Picea abies* stands. The four densograms are relatively similar in appearance.

Comparing bands 4 and 5, band 5 seems to be the most suitable because of its highest average density value and its smallest coefficient of variation. This is clearly seen by analyzing the distribution frequency shown in Figure 25. Because of the significant differences between bands 4 and 5, it is necessary to use only the second one.

In the same way, both bands 6 and 7 can be used for such an identification. Since band 7 has given the highest average density value, it seems to be the best one (see densograms and distribution of density frequency shown in Figures 31 and 37).

In short, to study pure *Picea abies* stands by means of densograms, the two bands most indicated are 5 and 7, though bands 4 and 6 can also be used (see Table 13).

10.8.2. Strip 2

Among bands 5 and 7 it is not easy to accurately state which is the best for identifying the forest cover studied in this strip, since the three bands all present very good characteristics. Band 5 has produced the highest average density value, but band 4 has shown the smallest coefficient of variation

(see Table 19). Probably, since statistical differences were not observed, any of the bands can be chosen with high chances of success (see Table 14).

10.8.3. Strip 3

As with strip 1, a good degree of accuracy in separating the forest cover could be obtained in the four bands by means of microdensograms (see Table 15 and Table 20).

Once again, it was difficult to choose the best band for the identification, but since band 5 presented the highest average density value and the smallest variation in the data, it was chosen as the best band for the purpose.

It is interesting to observe that in spite of the statistical differences between the three other bands, the absolute difference among their average density values is relatively small. In this case the relative frequency distribution was of important additional value. By analyzing Figures 21, 27, 33 and 39 one concludes that the best band for the differentiation is band 7.

10.8.4. Strip 4

As illustrated by Table 16, the statistical comparisons between the different strips are similar to those already made with strip 3. Also, in this case, based on the two parameters so far discussed (and the frequency distribution), band 5 can be selected as the best one.

10.8.5. Strip 5

In a similar way to the other test-strips, band 5 seems here to be the most suitable one, in spite of its statistical similarity to band 4 (see Table 17 and Table 20).

Also bands 6 and 7 are not statistically different, but their

distribution of tone frequency shows some irregularities (see Figures 35 and 41).

The best band for this case is band 5. Band 7 can also be used as complementary.

10.8.6. Strip 6

As seen in Table 18, the results are similar to those obtained from test strip 5.

10.9. Cluster Analysis of the Four Landsat - MSS Bands

The problems and successes in separating the different forest types are summarized in Figures 43 and 44. These figures represent a cluster analysis of the four bands involved.

These Figures (clusters) are based on analyses carried out with statistical significances of 70 %. By using higher levels of significance - for instance 95 % - the clusters became bigger and more overlapping was obtained.

The software for this analysis has been developed by G. Lange as part of the FIPS (Freiburger Image Processing System) Version.

10.9.1. Band 4 versus Band 6

As shown in Figure 43, pure Picea abies stands are easily recognized when these two bands are used. This combination is also excellent for identifying Picea abies/ mixed-coniferous stands apart from pure Picea abies. However, the old aged mixed-deciduous stands could not be separated from middle aged mixed deciduous and mixed deciduous/ P.silvestris stands. One of the reasons for the difficulty with the P. silvestris stands was the high percentage of deciduous present in the second unit.

In the case of test strip 6 - band 6 (middle aged mixed deciduous stands), it should be considered that the cluster was highly influenced by a small Pseudotsuga menziesii/Picea abies stand which unfortunately bordered the microdensogram (see Figure 36). The dispersion presented by the cluster obtained for band 6 would be smaller without the introduction in the analysis of the

density values corresponding to P. menziesii/Picea abies.

Mixed-forest stands are easily separated from pure Picea abies/mixed coniferous and old mixed deciduous stands; however, only part of these last units could be separated from mixed-deciduous/P.silvestris stands.

10.9.2. Band 5 versus Band 7

Also, in this combination (shown in Figure 44), pure P.abies stands were easily separated from other forest types.

A strong dispersion was observed in the P.abies/mixed-coniferous stands (strip 2). Unfortunately, this dispersion could not be controlled for reasons already discussed in the last sub-chapter. However, as shown in Figure 43, this forest type could be separated from others by using the bands 4/6 combination. If, therefore, cluster 2 is not included in the further discussion of Figure 44, one can observe that besides the pure Picea abies stands, also the old mixed-forests and the middle aged deciduous stands form clearly separated clusters. Only the old mixed deciduous stands and the middle aged deciduous/Pinus silvestris stands could not be differentiated.

Many combinations can be made for identifying forest types. The most important problem is to find the best combination in every situation. As observed by ANDERSON (1974), "Experience has shown that it is best to tailor keys or combinations individually for every local area".

Another combination is given in Figure 45. This combination can be very useful for future automated classifications in this area of study and is an example of a box classification (see HARDY and AGAR, 1977) for bands 4, 5 and 7.

The advantage of this classification lies in its three dimensional character. Three bands are used instead of two. The three dimensional space is defined by mutually orthogonal axes corresponding to the reflectivity values in the three bands. Any given reflectance value can be defined as falling within the box or outside the box. For constructing this "box or

cuboid model", data from Table 19 were used. This means that every reflectance value is situated at an interval ranging from plus to minus its standard deviation (mean $\pm$ st. dev.).

This is a good model but problems can be also seen in strips 2 and 4, as well as in strips 3, 5 and 6.

Finally, it is worth while to observe that reasonable and reliable success can be obtained by microdensitometric work on Landsat MSS data in forestry, as proved here and in some other studies (KUUSELA and POSO, 1975; ASHLEY and REA, 1975), in spite of the recommendation that only macrodensitometry should be undertaken (ERTS User's Handbook, 1972).

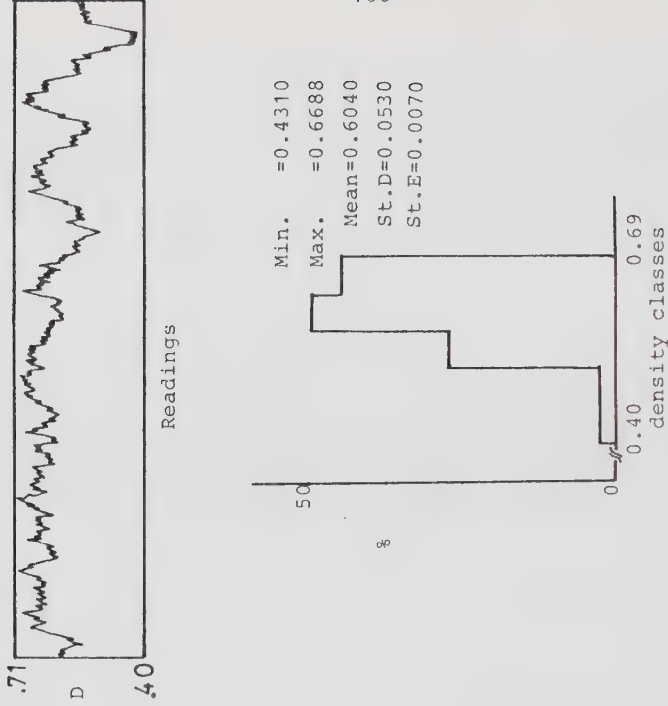


Figure 19. Microdensitogram of a pure old aged Picea abies stand with relative frequency distribution - Band 4

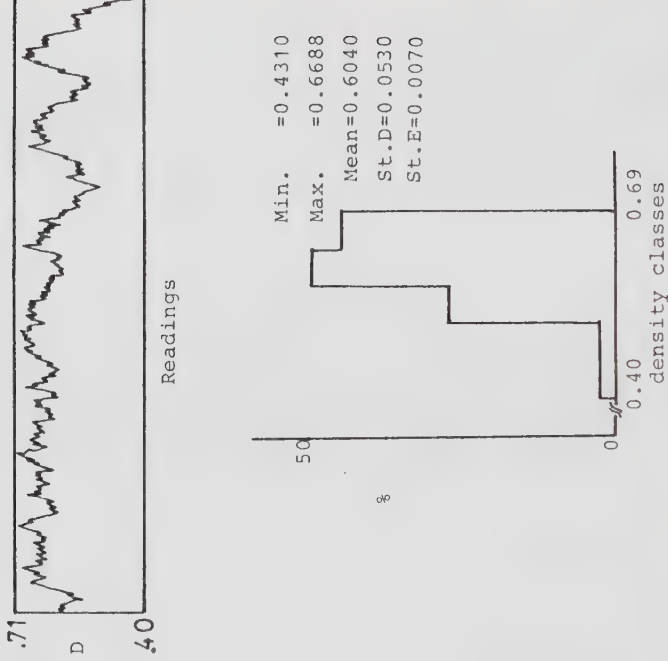


Figure 20. Microdensitogram of an old aged Picea abies/mixed-coniferous stand with relative frequency distribution - Band 4

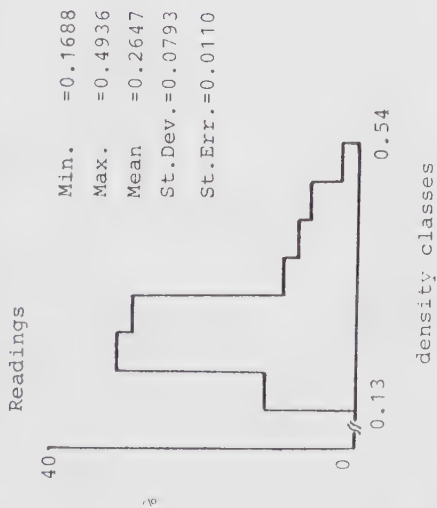


Figure 21. Microdensitogram of an old aged mixed-deciduous stand with relative frequency distribution - Band 4

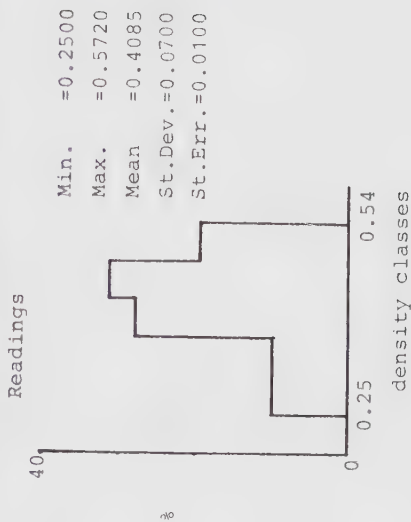
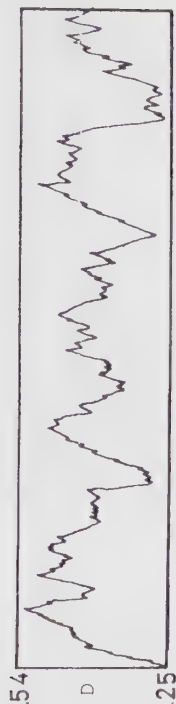


Figure 22. Microdensitogram of an old aged mixed-forest with relative frequency distribution - Band 4

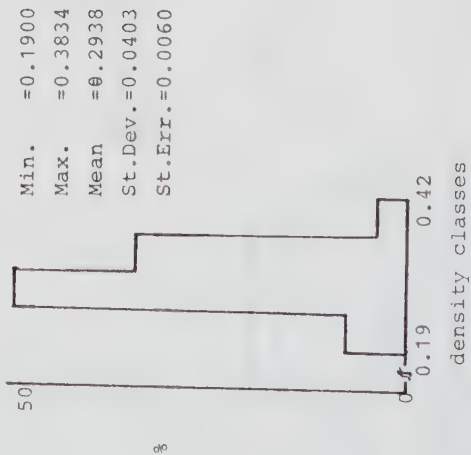
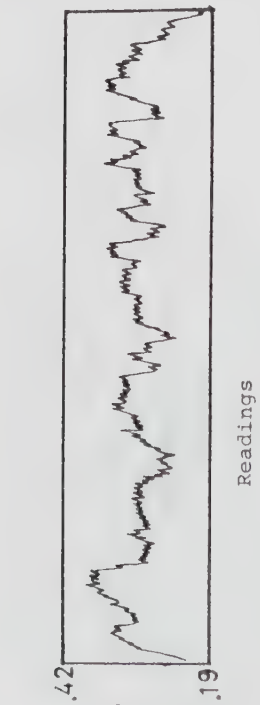


Figure 23. Microdensitogram of a middle aged mixed-deciduous/Pinus silvestris stand with relative frequency distribution - Band 4

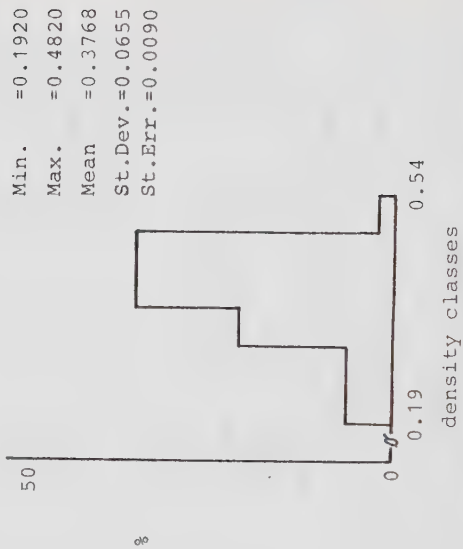
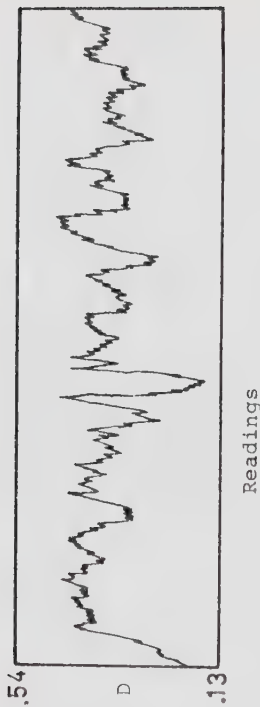
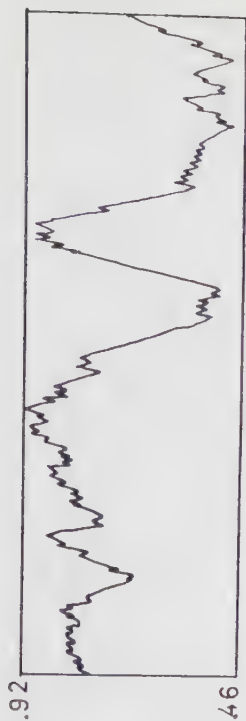


Figure 24. Microdensitogram of a middle aged mixed-deciduous stand with relative frequency distribution - Band 4



Readings

min.	=0.506
max.	=0.924
mean	=0.7234
st.dev.	=0.1364
st.err.	=0.0190

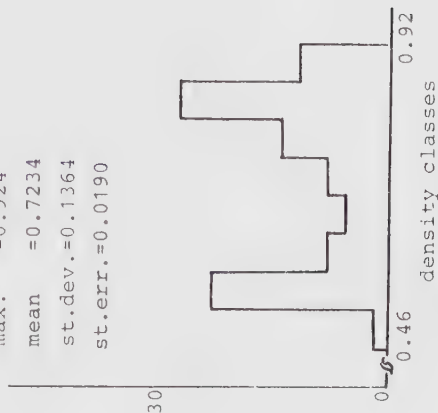


Figure 25. Microdensitogram of a pure old aged Picea abies stand with relative frequency distribution - Band 5

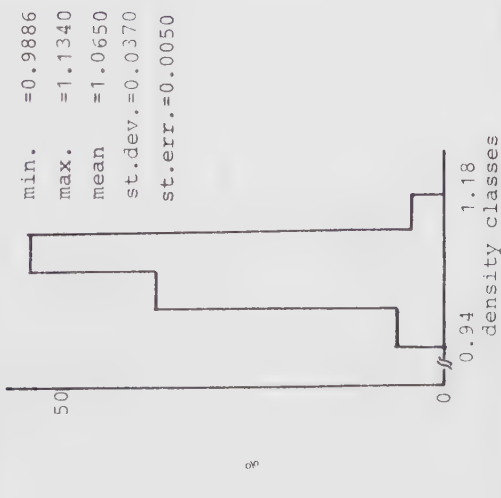
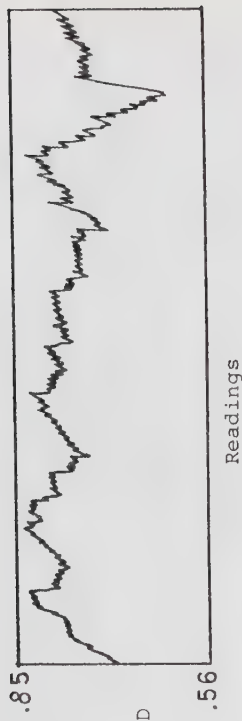


Figure 26. Microdensitogram of an old aged Picea abies/mixed-coniferous stand with relative frequency distribution- Band 5



Min. =0.5640
 Max. =0.8540
 Mean =0.7673
 St.Dev.=0.0581
 St.Err.=0.0080

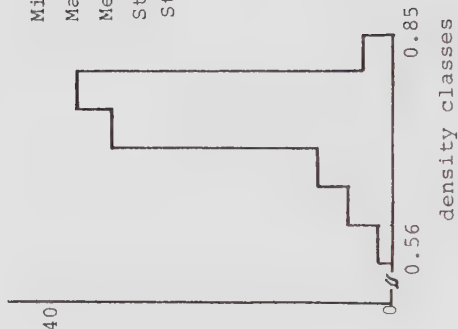
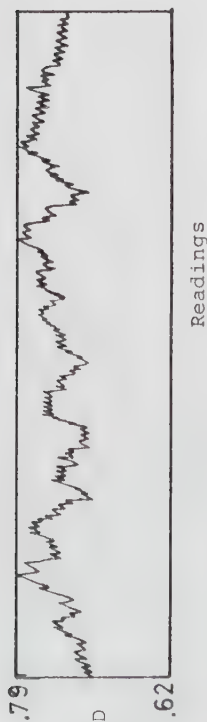


Figure 28. Microdensitogram of an old aged mixed-deciduous stand with relative frequency distribution - Band 5



Min. =0.6220
 Max. =0.7844
 Mean =0.6923
 St.Dev.=0.0420
 St.Err.=0.0060

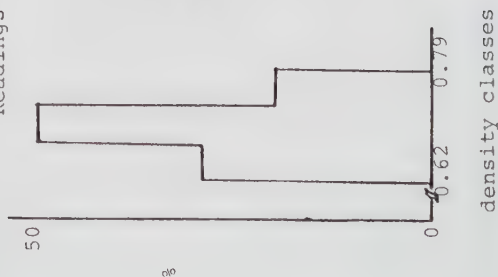
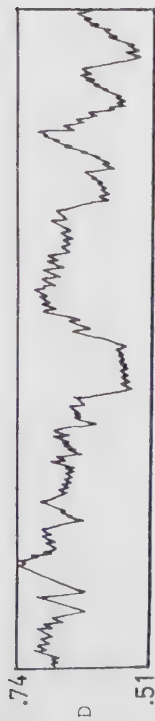


Figure 27. Microdensitogram of an old aged mixed-deciduous stand with relative frequency distribution - Band 5



Readings

Min. = 0.5060
 Max. = 0.7380
 Mean = 0.6236
 St.Dev. = 0.0580
 St.Err. = 0.0080

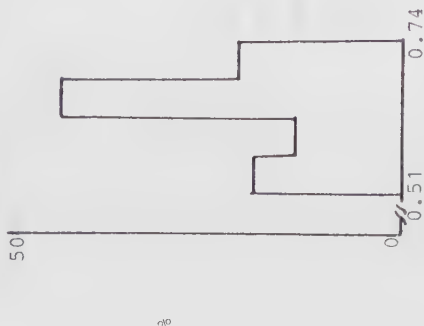
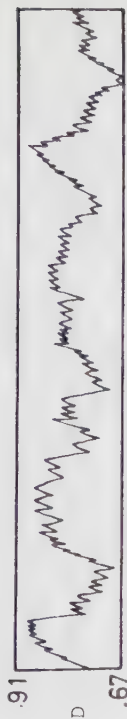
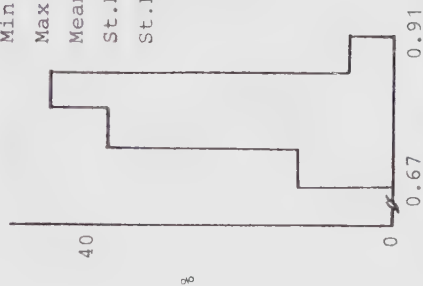


Figure 29. Microdensitogram of a middle aged mixed-deciduous/
Pinus silvestris stand with relative frequency distribution - Band 5



Readings

Min. = 0.6858
 Max. = 0.8714
 Mean = 0.7821
 St.Dev. = 0.0424
 St.Err. = 0.0060



density classes

Figure 30. Microdensitogram of a middle aged
 mixed-deciduous stand with relative frequency distribution - Band 5

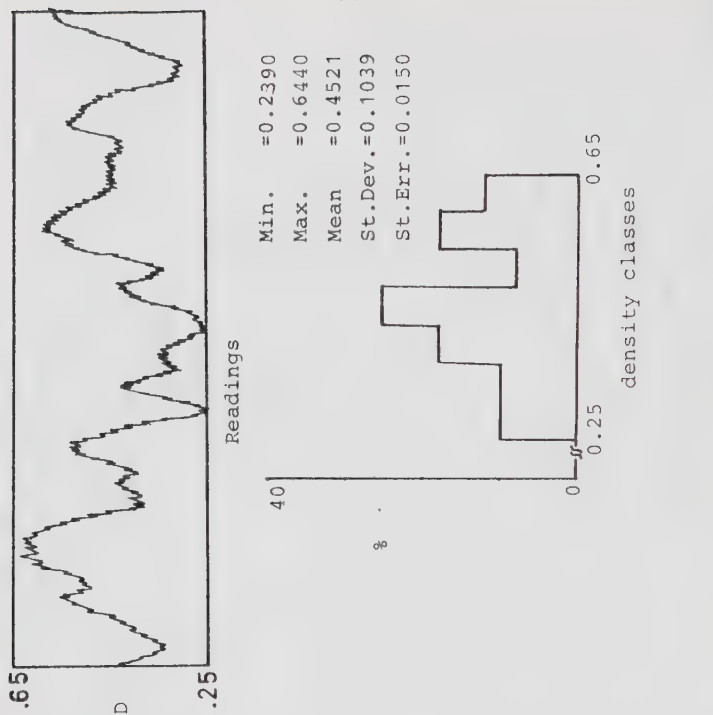


Figure 31. Microdensitogram of a pure old aged Picea abies stand with relative frequency distribution - Band 6

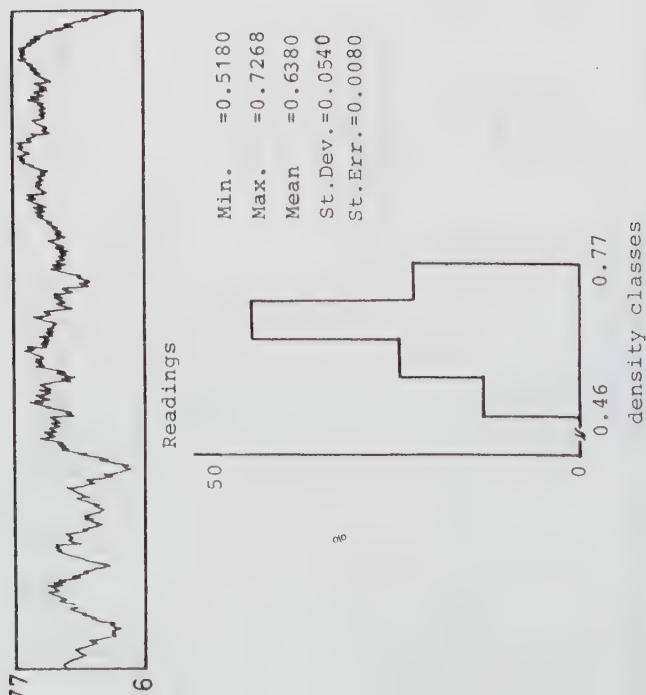
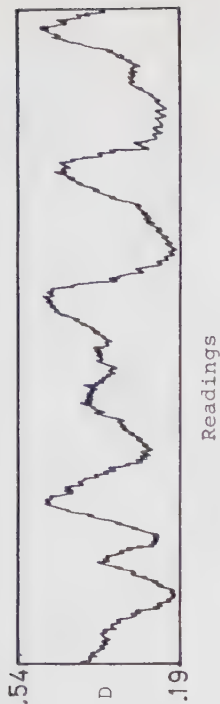
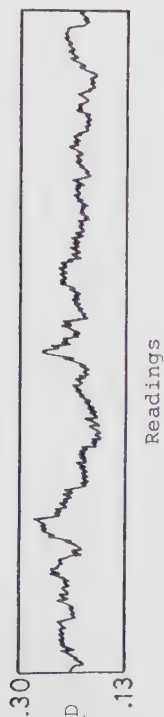


Figure 32. Microdensitogram of an old aged Picea abies/mixed-coniferous stand with relative frequency distribution - Band 6



Min. = 0.2210
 Max. = 0.5110
 Mean = 0.3592
 St.Dev. = 0.0790
 St.Err. = 0.0110



Min. = 0.1340
 Max. = 0.2558
 Mean = 0.1860
 St.Dev. = 0.2300
 St.Err. = 0.0040

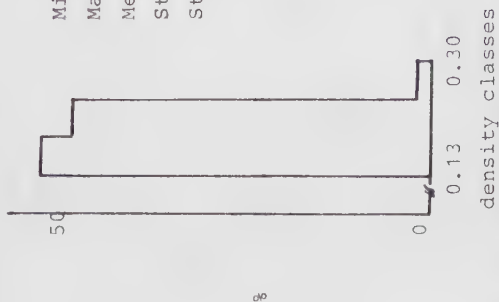


Figure 33. Microdensogram of an old aged mixed-deciduous stand with relative frequency distribution - Band 6

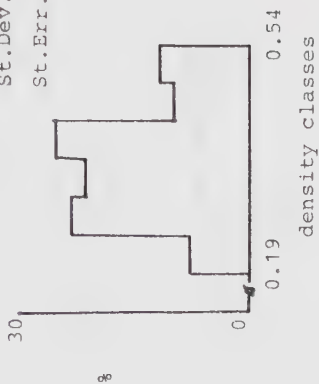


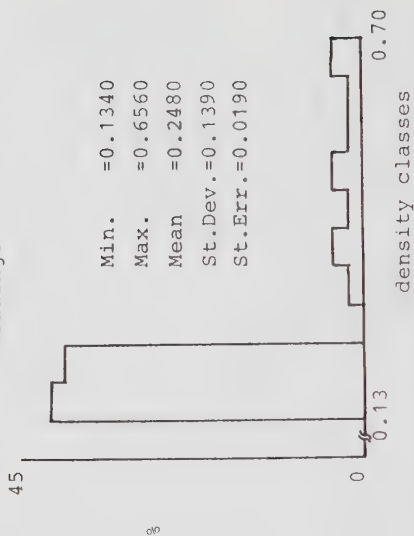
Figure 34. Microdensogram of an old aged mixed-deciduous stand with relative frequency distribution - band 6



Readings

Min. = 0.1688
 Max. = 0.5574
 Mean = 0.3396
 St.Dev. = 0.1150
 St.Err. = 0.0160

Min. = 0.1340
 Max. = 0.6560
 Mean = 0.2480
 St.Dev. = 0.1390
 St.Err. = 0.0190



density classes

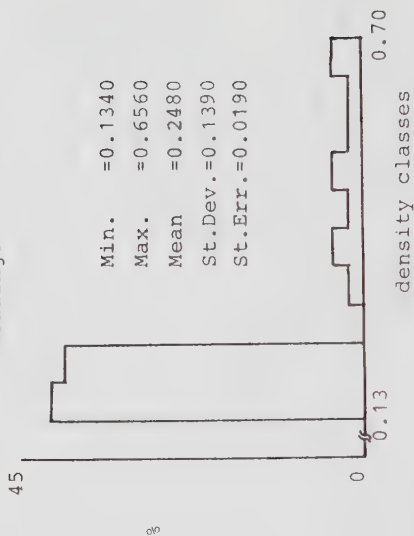
Figure 35. Microdensitogram of a middle aged mixed-deciduous/*Pinus silvestris* stand with relative frequency distribution - Band 6



Readings

Min. = 0.1688
 Max. = 0.5574
 Mean = 0.3396
 St.Dev. = 0.1150
 St.Err. = 0.0160

Min. = 0.1340
 Max. = 0.6560
 Mean = 0.2480
 St.Dev. = 0.1390
 St.Err. = 0.0190



density classes

Figure 36. Microdensitogram of a middle aged mixed deciduous stand with relative frequency distribution - Band 6



Min. = 0.2616
 Max. = 0.8300
 Mean = 0.5021
 St.Dev. = 0.1812
 St.Err. = 0.0250

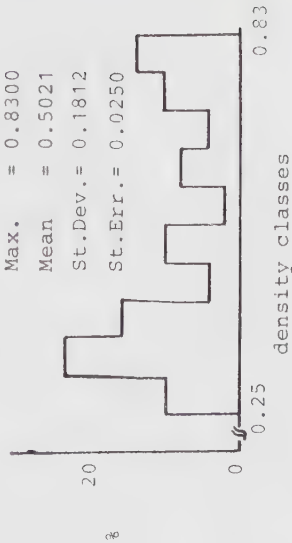
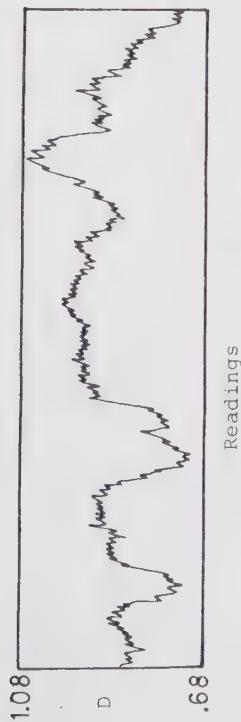


Figure 38. Microdensitogram of an old aged mixed-coniferous stand with relative frequency distribution - Band 7



Min. = 0.7089
 Max. = 1.0222
 Mean = 0.8830
 St.Dev. = 0.0766
 St.Err. = 0.0110

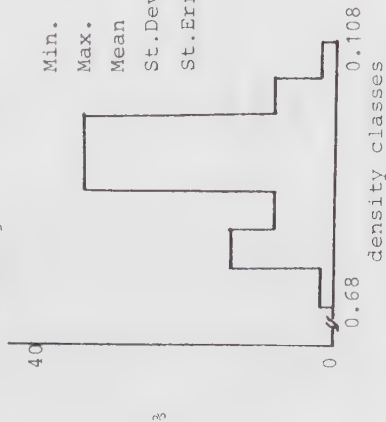


Figure 37. Microdensitogram of a pure old aged *Picea abies* stand with relative frequency distribution - Band 7

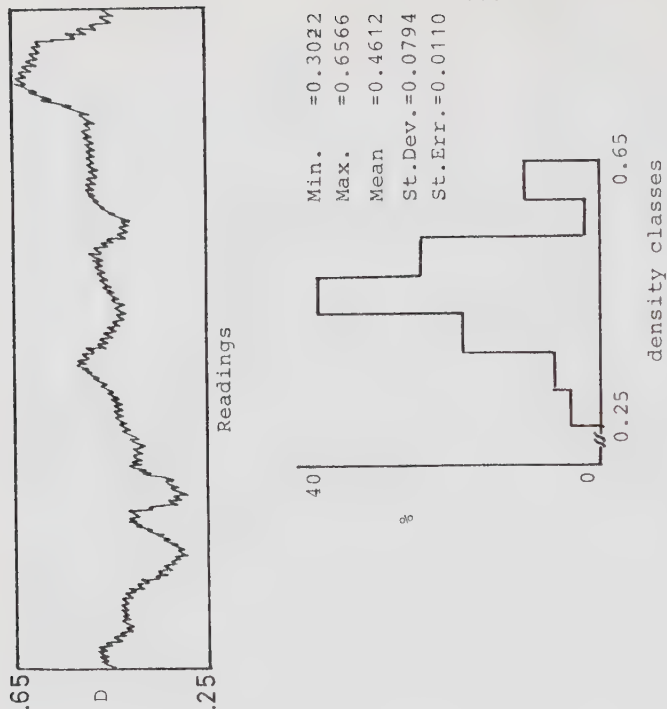
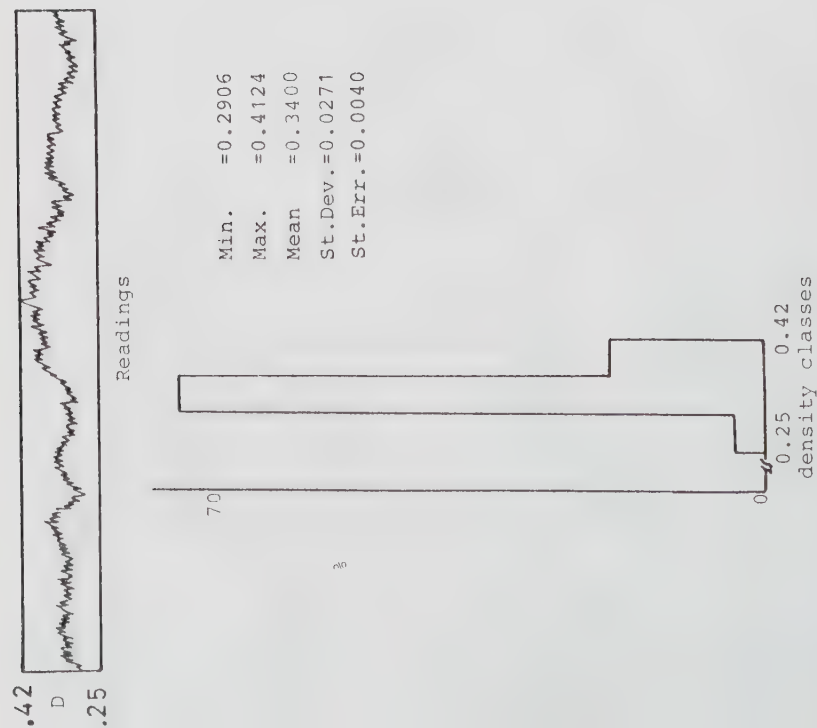


Figure 39. Microdensogram of an old aged mixed deciduous stand with relative frequency distribution - Band 7

Figure 40. Microdensogram of an old aged mixed forest stand with relative frequency distribution - Band 7



Min. = 0.2500
 Max. = 0.6154
 Mean = 0.3645
 St.Dev. = 0.0892
 St.Err. = 0.0120

Min. = 0.1804
 Max. = 0.3080
 Mean = 0.2507
 St.Dev. = 0.0327
 St.Err. = 0.0050

8



Figure 41. Microdensogram of a middle-aged mixed-deciduous/Pinus silvestris stand with relative frequency distribution - Band 7

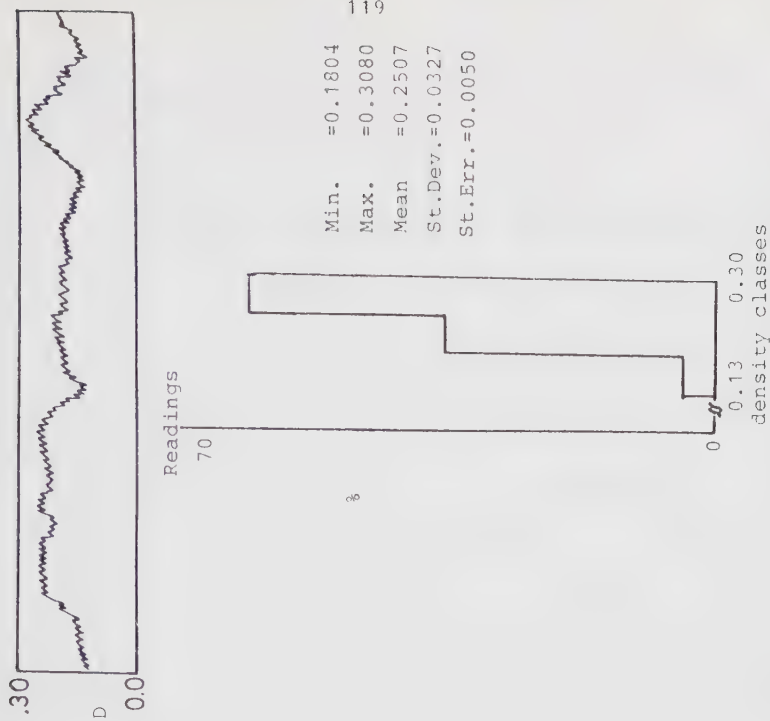
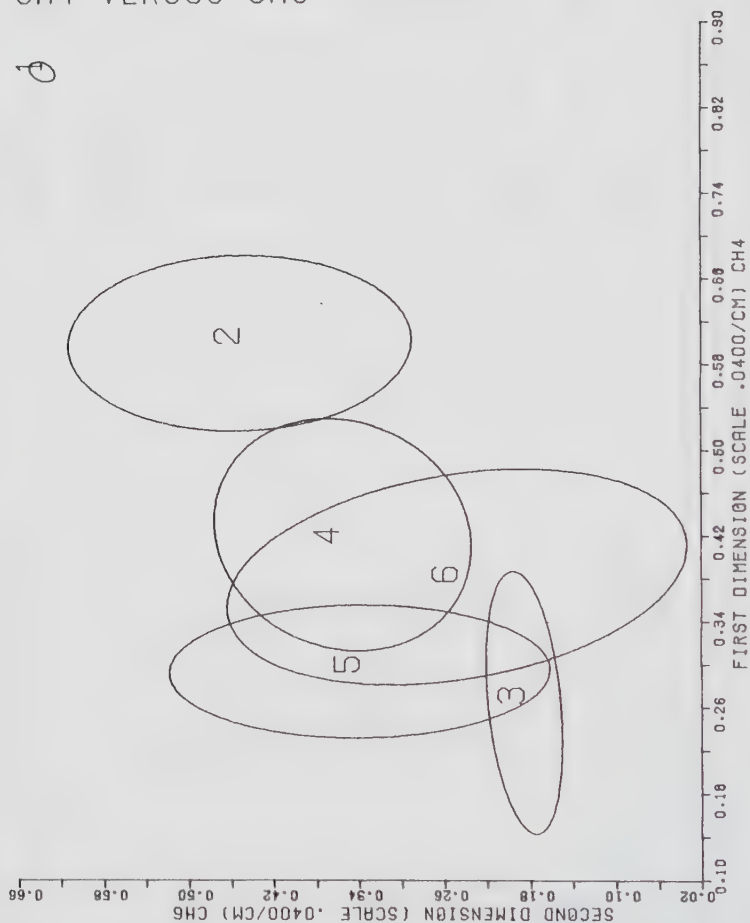


Figure 42. Microdensogram of a middle-aged mixed-deciduous stand with relative frequency distribution - Band 7

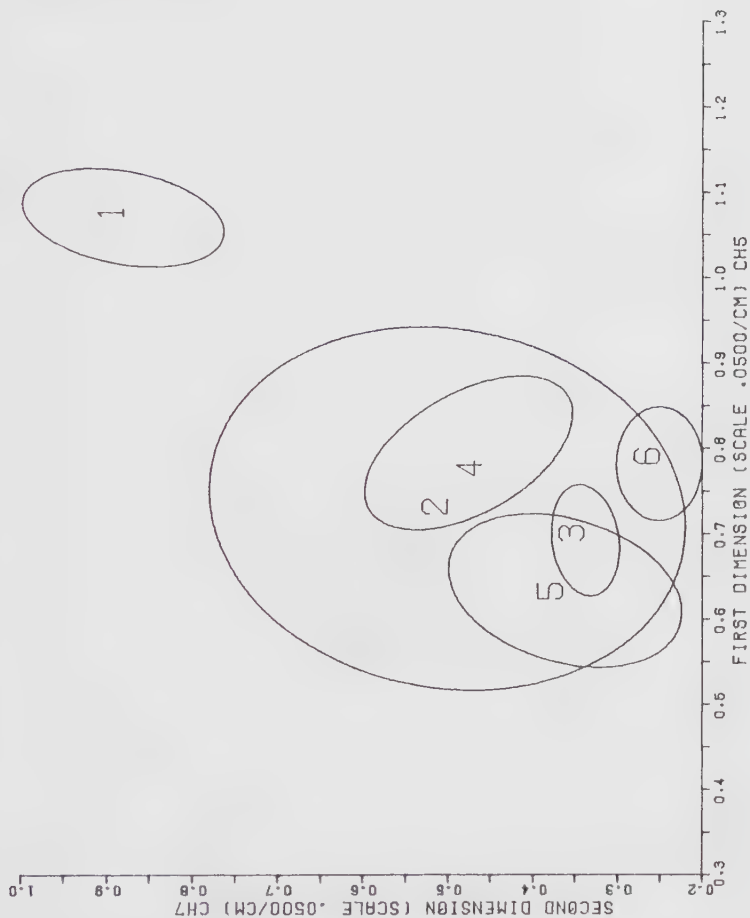
CH4 VERSUS CH6



FIPS VERSION 091178 EXECUTED AT 11:04:16 ON NOV. 07, '78
MODULE PEEBN, CURR VERSION 103178, BY GUIDO LANGE

Figure 43. Statistical clusters of density values for
bands 4 and 6

CH5 VERSUS CH7



FIPS VERSION 091178 EXECUTED AT 11:07:47 ON NOV. 07, '78
 MODULE PEEEBN, CURR VERSION 103178, BY GUIDO LANGE

Figure 44. Statistical clusters of density values for
 bands 5 and 7

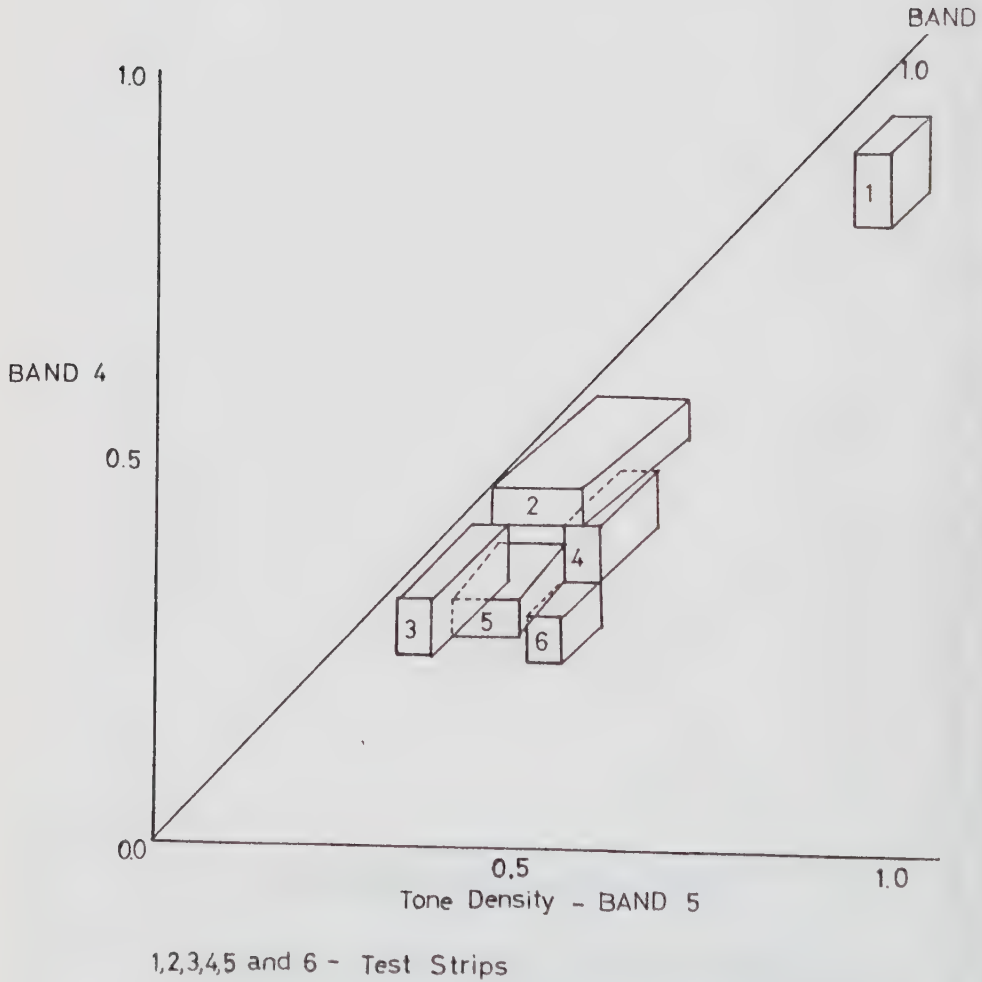


Figure 45. Model of a "box or cuboid classification" for the area of study

Table 12. Statistical significance (according to the t-test) between Landsat bands and test-strips in the area of study

Bands	strip	1	2	strip 3			4	5	6
4	1		s	s	s		s	s	s
4	2			s			s	s	s
4	3						s	n.s	s.
4	4							s	n.s.
4	5								s
5	1		s	s			s	s	s
5	2			n.s.			n.s.	s	s
5	3						s	s	s
5	4							s	n.s.
5	5								s
6	1		s	s			s	s	s
6	2			s			s	s	s
6	3						s	s.	n.s
6	4							n.s.	s
6	5								s.
7	1		s	s			s	s	s
7	2			s			n.s.	s.	s
7	3						s	n.s	s
7	4							s	s
7	5								s

s = The difference is statistically significant at 0.01 probability level
n.s. = The difference is not statistically significant at 0.01 probability level

Table 13. Statistical Combination of bands for Test-strip 1 *

	Band 5	Band 6	Band 7
Band 4	22,134 s.	23,48 s.	3,76 s.
Band 5	-	41,68 s.	11,476 s.
Band 6	-	-	20,647 s.

Table 14. Statistical Combination of bands for Test-strip 2. *

	Band 5	Band 6	Band 7
Band 4	6,009 s.	9,216 s.	3,775 s.
Band 5	-	11,304 s.	6,980 s.
Band 6	-	-	1,712 n.s.

Table 15. Statistical Combination of bands for Test-strip 3 *

	Band 5	Band 6	Band 7
Band 4	29,694 s.	4,675 s.	6,931 s.
Band 5	-	49,961 s.	34,650 s.
Band 6	-	-	23,058 s.

Table 16. Statistical Combination of bands for Test-strip 4 *

	Band 5	Band 6	Band 7
Band 4	25,161 s.	3,062 s.	3,273 s.
Band 5	-	29,788 s.	22,343 s.
Band 6	-	-	6,497 s.

s. - The difference is statistically significant at 0.01 probability level.

n.s. - The difference is not statistically significant.

* - According the t - test ($t_{.01} = 2,682$)

Table 17. Statistical Combination of bands for Test-strip 5*

	Band 5	Band 6	Band 7
Band 4	29,981 s.	2,694 s.	5,160 s.
Band 5	-	15,268 s.	16,503 s.
Band 6	-	-	1,226 n.s.

Table 18. Statistical Combination of bands for Test-strip 6 *

	Band 5	Band 6	Band 7
Band 4	37,115 s.	6,872 s.	12,290 s.
Band 5	-	27,667 s.	70,853 s.
Band 6	-	-	0,969 n.s.

s. - The difference is statistically significant at 0.01 probability level.

n.s. - The difference is not statistically significant.

Table 19. Comparison of image statistics of the six test-strips in the area of study

CLASS	Band 4			Band 5		
	$\bar{X}$	s	CV %	$\bar{X}$	s	CV %
Strip 1	0.8543	0.0413	4.84	1.065	0.037	3.47
Strip 2	0.6014	0.0509	8.47	0.723	0.136	18.82
Strip 3	0.2647	0.0793	29.95	0.692	0.042	6.06
Strip 4	0.4145	0.0700	16.88	0.767	0.058	7.57
Strip 5	0.2938	0.0403	13.72	0.6236	0.058	9.30
Strip 6	0.3768	0.655	17.38	0.7821	0.042	5.40
(continued)				Band 7		
	$\bar{X}$	s	CV %	$\bar{X}$	s	CV %
Strip 1	0.638	0.054	8.46	0.8830	0.076	8.61
Strip 2	0.452	0.103	22.98	0.5021	0.181	36.08
Strip 3	0.186	0.023	12.36	0.3400	0.027	7.83
Strip 4	0.359	0.079	21.99	0.4612	0.079	17.21
Strip 5	0.339	0.115	33.83	0.3645	0.089	24.46
Strip 6	0.248	0.139	56.04	0.2507	0.033	13.16

$\bar{X}$ - Average value of class spectral radiance

s - Standard deviation

CV - Coefficient of Variation

Table 20. Comparisons of densograms statistics in the four Landsat - MSS bands and the interaction among the six test-strips in the area of study.

Test-strips	Band 4	Band 5	Band 6	Band 7
1 versus 2	27,208 s.	15,930 s.	10,496 s.	14,435 s.
1 versus 3	47,081 s.	31,391 s.	45,920 s.	49,026 s.
1 versus 4	34,108 s.	26,931 s.	19,646 s.	28,388 s.
1 versus 5	69,317 s.	36,895 s.	15,978 s.	32,640 s.
1 versus 6	44,009 s.	30,291 s.	19,202 s.	55,956 s.
2 versus 3	25,527 s.	1,466 n.s.	15,956 s.	6,105 s.
2 versus 4	14,059 s.	2,120 n.s.	5,082 s.	1,476 n.s.
2 versus 5	33,817 s.	4,685 s.	5,184 s.	4,879 s.
2 versus 6	19,328 s.	2,935 s.	9,209 s.	9,744 s.
3 versus 4	8,909 s.	6,097 s.	12,570 s.	9,863 s.
3 versus 5	2,346 n.s.	5,204 s.	7,825 s.	1,438 n.s.
3 versus 6	7,784 s.	8,171 s.	1,189 n.s.	16,118 s.
4 versus 5	8,822 s.	11,496 s.	1,005 n.s.	3,490 s.
4 versus 6	2,130 n.s.	1,408 n.s.	5,796 s.	17,541 s.
5 versus 6	7,706 s.	14,151 s.	4,331 s.	8,556 s.

s. - The difference is statistically significant at 0.01 probability level

n.s. - The difference is not statistically significant

t = 2,682 (table)

11. COMPUTER ASSISTED CLASSIFICATIONS

The automated classifications were carried out at the installations of the German Aerospace Research Center (DFVLR - Deutsche Forschungs- und Versuchsanstalt für Luft und Raumfahrt e.V.) in Oberpfaffenhofen, using the facilities (hardware and software) of the DIBIAS system (Digitales Bildauswertungssystem/Digital Image Interpretation System).

Hardware

According to NOWAK (1977), see also FERNANDEZ et al (1975), "the central processing unit of the DIBIAS system is an INTER-DATA Model 85 with 64 kbyte of semiconductor main storage. Apart from the usual system components which are necessary for running such a computer (such as discs, magnetic tapes, card reader, printer, etc.), the system is equipped with the following devices which were chosen especially for the interactive image processing:

An alphanumeric terminal with keyboard allows communication between DIBIAS and the user. It is possible

- to start the different image processing programs,
- to read parameters into a program,
- to verify the actual status of the system,
- and to receive system messages.

A color TV screen enables the user to verify the results of each processing step. With this feature, time and cost consuming exposure and development of films is avoided. In addition, there is the possibility to interact directly with the image data on the screen via track-ball and light-target.

A graphic terminal is used for the display of graphic information such as histograms, grey level distributions, etc.

A mechanical drum scanner is used to digitize black and white photographs up to a size of 20 by 20 cm². A drum recorder is

used to produce black and white photographs.

A flying spot scanner is used to digitize black and white and color transparencies from 35 to 70 mm. film.

Recording of black and white and color film is carried out by an electronic film recorder which is also able to expose polaroid films".

For a better understanding of the hardware concept, see Figure 46.

Software, see NOWAK, 1977.

"Application and effectiveness of such an image processing system depend highly on the flexibility of the software. The following concept of programs was developed during 1975 and 1976 under the aspect of optimal man-machine interaction.

The user may read image data into the DIBIAS system by activating the appropriate input program. He may then enhance, classify or otherwise process his image by giving the necessary commands to the system. The system supplies him with interpretation aids (e.g. histograms), with some additional information about the processing with system messages, and with tutorial information. Finally, the user may produce a hard copy of the image on one of the output devices."

The software concept can be better visualized with the help of Figure 47. The processing modules can be subdivided into the following subsets:

- elementary image enhancement,
- multispectral classification,
- digital filtering,
- texture analysis and
- programs to process data on the interactive TV screen.

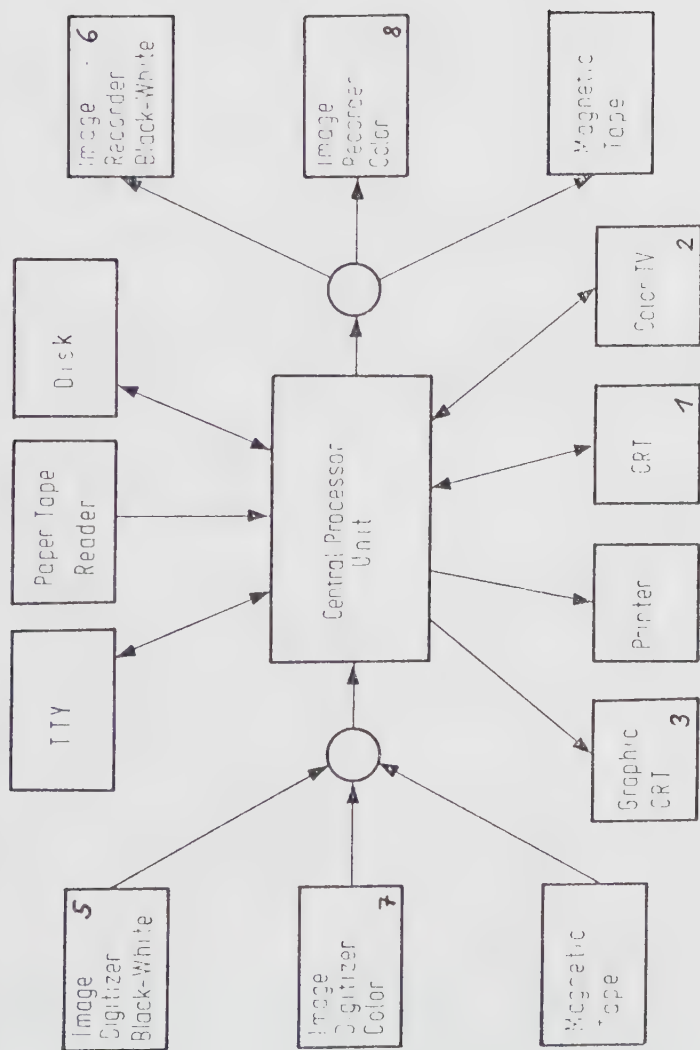


Figure 16. Block Diagram of the DIBIAS Hardware (from NOWAK, 1977)

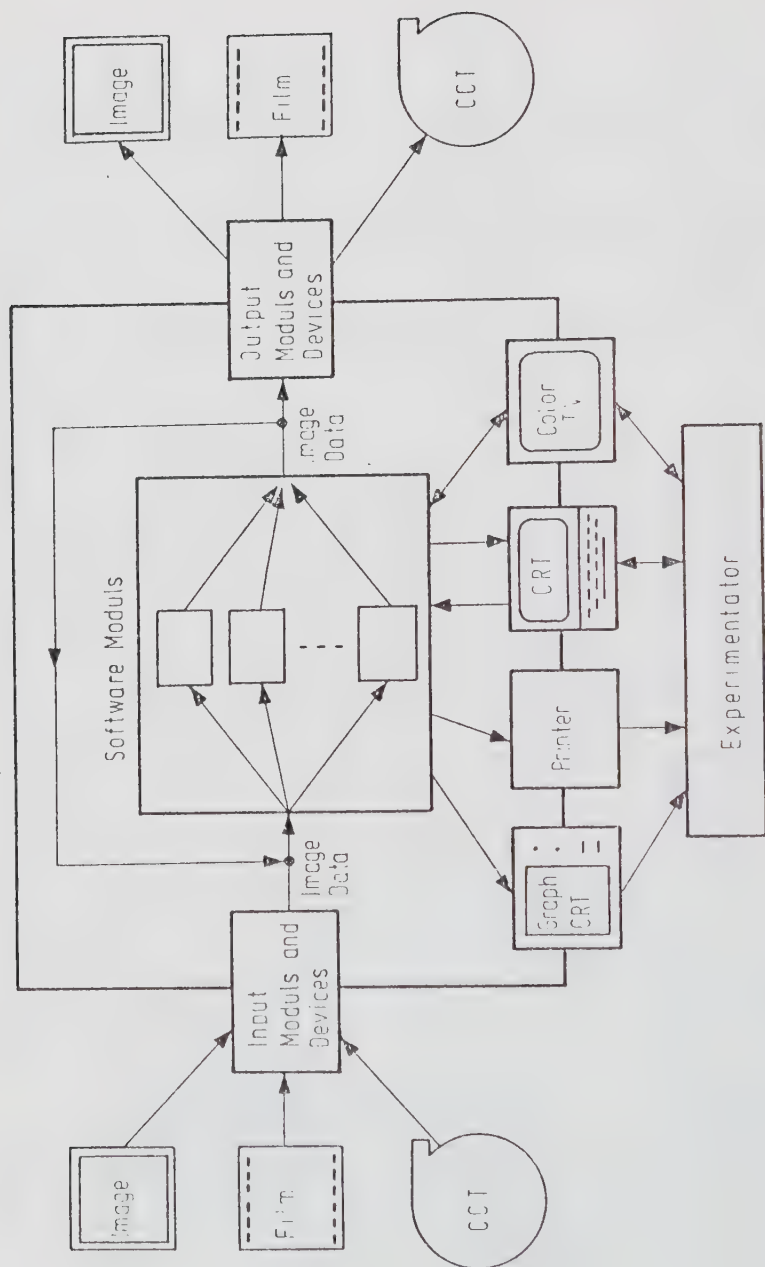


Figure 47. Block Diagram of the DIBIAS System (from NOWAK, 1977)

11.1. Ground Truth and Selection of Training Sets

"Ground truth", as used here and in previous sections, refers, as cited by LACHOWSKY and DIETRICH (1977) and many others, to "any combination of information about ground observations, measurements from topographic and other maps and information from aerial photographs that aid in identifying various cover types during the analysis of satellite data".

For establishing the ground truth, color infrared airphotos at a scale of 1:11,000, acquired in July 1976 (see WEAR, 1978), were used as well as B/W imagery of the infrared - channels of the airborne Bendix M²S - Multispectral Scanner operated from flight levels of 1000, 2000 and 4000 m. above sea level. Additional field data were also obtained from various Forest Services.

The produced overlays were transferred to base maps (1:25.000) through an aerosketchmaster.

The area corresponding to the automatic classification was measured on the base maps with the aid of a polar planimeter. As in the three other previous phases, one of the problems was the map legend. It was decided to carry out two different interpretations (considering only the level of accuracy as a factor of differentiation):

- The first one, in an area of approximately 1000 ha. was very detailed, with delineation of coniferous and deciduous stands according to different degrees of crown closure and age classes (see 11.4.).

- The second one was not so detailed; its accuracy delineation was somewhat regional, presenting, in one level, coniferous and deciduous stands and, in another (a little more detailed), old dense stands of Picea abies and middle aged stands of Pinus silvestris.

It was observed that data of the first computer assisted classifications (very detailed) were of little use for the region

of study because of its extensive area. This problem will be discussed later (see 11.4.).

The second case presented satisfactory results and easily met the requirements of the level of accuracy I. Similar experiences are also reported by KALENSKY (1974, 1975), HOFFER et al (1976), MEAD and MEYER (1977) among many others.

From the entire scene, representative test areas were selected with the aid of a track ball whose movements were controlled on the TV screen with continuous reference to the base map (interactive process). By doing so, the statistics of each test area and band were obtained through the line printer (Determination of object signatures). These statistics (average density value, standard deviation, co-variance matrix, etc. were used by the program for the following classifications.

About 10 per cent of the entire area was used as training sets for acquiring the necessary statistics and good results were obtained. HOFFER et al (1975), in a similar situation, derived very significant classification accuracy (94%) using only 0,1 % of the total data set.

Presented only as an example, Figure 48 shows statistics of the training sets for *Picea abies*. These statistics and other histograms of relative photographic density were obtained in a similar way to that already seen in the study of microdensograms (see Chapter 10).

A problem related to the extraction of "clean" signatures was that some forest types did not seem to present significantly different spectral signatures (see also VICEK, 1974).

11.2. Qualitative Analysis

Detailed descriptions about supervised and unsupervised procedures of automatic classification are found in PRESTON (1975). HOFFER et al (1975, 1976), BERKEBILE, et al (1976) and were already discussed in Chapter 2 of the present study. The class-

ification algorithm applied in the DIBIAS system is described by HABERÄCKER (1977)¹. In this study only the multispectral signatures of the objects considered were used for the classification.

10.2.1. Supervised Maximum Likelihood Classification

Two test areas were selected. The first (Rhine Valley - Foot-hills) is illustrated in Figure 49. The second was located in an entirely mountainous area of the Black Forest.

The classification itself was based on the Maximum Likelihood (ML) algorithm, and the optimal number of classes in this case was 4 (only forest classes were considered), although an attempt was made to obtain more forest classes without significant success.

The classified units in test area 1 (Figure 49) were:

- N^o 1 Pinus silvestris stands (displayed in olive green);
- N^o 2 Mixed deciduous - including mixed-forests with high of deciduous (displayed in white);
- N^o 3 Mixed coniferous stands, pure Picea abies and mixed - forests with predominance of coniferous (displayed in yellow);
- N^o (4) Unclassified areas (agricultural, urban areas, etc.) - displayed in Black

The geometric fidelity of the vegetation units, despite being considered a good one, was still somewhat inferior to the unsupervised method especially in rugged areas with small valleys among mountains. This was also visible in flat areas, as in the case of the "Südlicher Mooswald" and the "Regatta See" (approximately at the center of the image). Another factor was "misclassification" found in the case of some "Pinus silvestris" stands near the urban areas (though these stands were not in the observed proportions of the image). However, this will be better studied in the quantitative analysis (see 11.3.1.).

¹ HABERÄCKER, P. Multispectral Classification in DIBIAS.

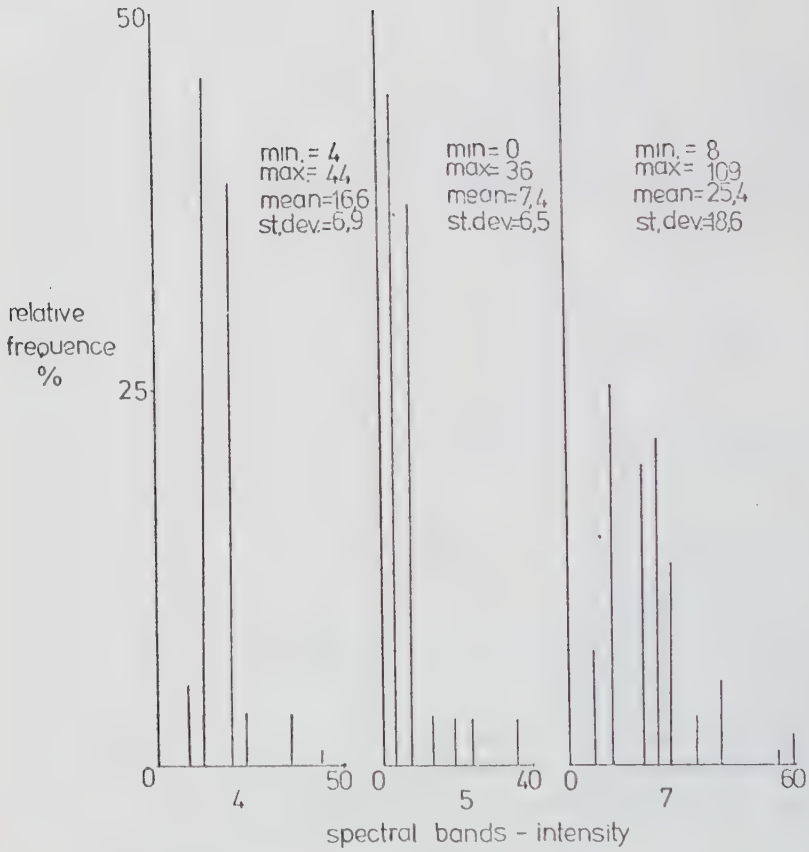
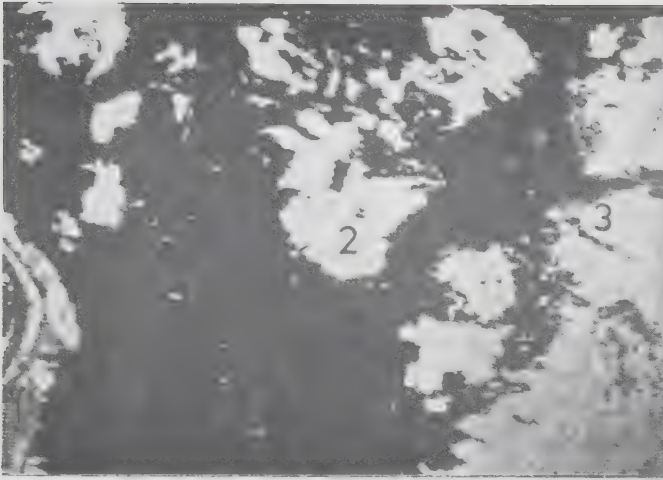


Figure 48. Basic statistics for Picea abies (example of computations)



Classes 1 - 3
and (4) (black)
see page 133

Figure 49. Illustration of the supervised ML classification carried out in the area of study



4-Yellow- Agricultural fields
5-Olive green-Mixed deciduous
6-Red brown-Mixed forests
7-Dark blue-P.silvestris
8-Dark violet- Picea abies
9-Light brown- Young mixed
coniferous stands

Figure 50. Illustration of the unsupervised MD classification carried out in the area of study

The second supervised classification was carried out in an entirely mountainous area of the Black Forest. In this case, pure Picea abies stands were displayed in olive green; mixed-deciduous in light blue (also transitory states between fields with a few trees and deciduous stands were displayed in light blue); mixed coniferous stands with percentages of about 50% of Picea abies were registered in dark blue color; P.silvestris stands (very dark blue) and unclassified areas (grass, lakes, etc.) in dark red.

The geometric fidelity of this classification was also excellent, although in rugged areas it is always inferior when compared with flat areas. In addition, the rapid recognition of specific areas on maps and airphotos is more difficult.

11.2.2. Unsupervised Minimum Distance Classification (MD)

The qualitative analysis for this method was concentrated primarily in the classifications carried out in test area 1 (Rhine Valley - Black Forest).

Figure 50 illustrates the obtained classification results. According to the line printer sheet, 13 classes were classified (both forest and non-forest) with each class displayed in a specific color with a per mile ray of error equal to 40, using the minimum distance classifier. For the purpose of this study only four of the thirteen classes were considered, namely: mixed-deciduous (displayed on olive green), mixed-forest (red brown), pure old aged Picea abies stands (dark violet) and Pinus silvestris (dark blue). The "other classes" refer to roads, vineyards, agricultural fields and other non-forest areas. In flat areas, the perfect delineation of forest stands was possible. Areas in the foothills and mountains also displayed a great fidelity in boundary delineation.

11.3. Quantitative Analysis

For the automatic mapping, Landsat CCT, scene number 2199 - 09374, of August 9, 1975, corresponding to bands 4, 5 and 7, was used. Only single date data were used because, as stated by many authors, temporally registered data add too much complexity to the signatures and do not improve the accuracy appreciably (see KAN, 1978).

11.3.1. Supervised Maximum Likelihood Classification (ML)

For test area 1

The quantitative evaluation, using the ML classification results obtained from the line printer sheet, was only applied in the supervised procedure, since it was impossible to get direct tabulation of the classified forest types in the unsupervised MD classification.

Basically, two methods of accuracy evaluation were tested:

The first used planimetering of the ground truth maps and then compared the results with the results of the classification obtained from the line printer sheet (see Table 21).

The second, used an overlay with a net of squares (1cm. x 1 cm.) for both the ground truth and the computer classification.

For the first method, the results of acreage determination obtained from the computer as well as the planimetering of the ground truth maps are shown in Table 21. The coefficient of correlation among the estimates was very high ($r = +0.99407$) indicating, in advance, a good correspondence in acreage determination.

Considering the ground truth as the starting point for estimating the computer's mapping accuracy and assuming that each class unit corresponds to an accuracy of 100%, the corresponding class obtained via computer will have an accuracy of X. From this concept, 13.760,00 ha. of the forest land in the base-map correspond to 100%, Since 15.272,00 ha. were obtained by the automatic process, there exists a commission error - that is, more forest resources were interpreted than the existing ones. The mathematical relation is an inverse one, which enables us to obtain an overall accuracy performance of 89,00%. Considering the same mathematical relation for the different classes, an accuracy was obtained for mixed coniferous of 93,40%, for mixed-deciduous of 83,20% and for P. silvestris of 86,50%. The average class performance was 87,17% (about 1,30% smaller than the overall accuracy.)

Table 21. Comparison of acreage determination between ground truth and computer classification

Class No	Forest Type	Ground Truth			Computer Classification				Error
		ha.	%	%	Pixel	ha.	%	%	
3	Mixed								
	Conifers (mount.)	6215	45,2	13,5	14620	6624	43,4	14,4	+6,6
2	Mixed								
	Deciduous	7013	51,0	15,2	18072	8188	53,6	17,8	+16,8
1	<u>Pinus silvestris</u>								
	(flat area)	532	3,8	1,2	1015	460	3,0	1,0	-13,5
	Forest Land total	13760	100,0	29,9	33707	15272	100,0	33,2	+ 11,0
(4)	Unclassified								
	area	32240		70,1	67821	30728		66,8	- 4,7
	Test area total	46000		100,0	101528	46000		100,0	

Another similar way of obtaining the average class accuracy is shown in Table 21 in the error column. With this process, one has a very good idea of omission and commission errors.

In order to test the mapping accuracy by means of confusion tables and in order to have a relative idea of commission and omission errors (see COLWELL, 1976 and SIELSER and PATTERSON, 1975) as well as the real applicability of these tables in this test area, the details of the base maps were transferred to a scale of 1:50,000, while a sampling net with 1596 squares (1 cm. x 1 cm.) was simultaneously applied. Each square corresponded in this scale to an area of 25 ha. For these squares 530 were occupied by forest land, 100 squares were randomly selected from deciduous stands, 100 from coniferous stands and 20 from Pinus silvestris stands. (The results from the Pinus silvestris stands were later multiplied by a factor of 5 in order to create a basis for comparisons).

Also, an overlay using the same scale was later placed on the satellite computer interpretation, and the differences were measured in terms of coincidence. The Landsat CCT was system corrected but still had some small distortions. Because of this, the most central area of the image was selected (approximately 90% of the entire area) in an attempt to minimize possible problems due to spatial distortions. The result was highly satisfactory, though the test procedure was time consuming.

Table 22 illustrates the results obtained from the second method of mapping accuracy estimation.

Analyzing Table 22, it can be observed that deciduous stands were "confused" with (4) in 9% of the cases. This "confused" class corresponds to those pixels not classified (66,80%), a fact which is mainly due to the spectral similarity among vineyards and grasses when compared with deciduous stands. This is especially evident in areas with rugged topography.

Table 22. Confusion table used for test area 1
- Supervised classification

Forest Type (Fig 49)	Test Squares n	Test Squares Classified Correct as Type				Correct Classified n = %	Omission n = %
		1	2	3	(4)		
1	100	80	7	0	13	80	20
2	100	2	89	0	9	89	11
3	100	0	7	93	0	93	7
(4)	0	0	0	0	0	-	-
Comission n = %	-	2	14	0	22	-	-
Inventory result n	300	82	103	93	22	-	-
Deviation n		-18	+3	-7	+22	-	-
Average accuracy performance in %						87,33	-

With regard to coniferous stands, the possibility of interpretation seems to be better than for deciduous. Even so, some "confusion" was also observed (7%), despite the distinct spectral signatures of both covers. This problem could have arisen during the ground truth preparation when some deciduous stands (considered small ones) were introduced into the coniferous stands. Apparently, these stands comprised a maximum of 10% of the mixture, but really their percentage must have been higher as is visible in the computer classification. This is also seen in Table 21 where the acreage estimation for deciduous stands is compared with the corresponding ground truth.

In the second level of precision for this area an attempt was made to separate Larix sp., P. menziesii, Picea abies, and Pinus silvestris. However, the separation of the first three of these was difficult due to the similar spectral signatures and to the problem of obtaining pure stands for the extraction of representative training sets. Also, it should be noted that

the stands occurred in very small areal extensions, considering the Landsat resolution. Exceptions were the P. silvestris stands when they were found homogeneously in representative areal extensions (10 15,28 pixels) and when they were delimited by deciduous stands which highlighted the spectral contrast especially in flat areas. If these stands had occurred in rugged terrain, perhaps one could have obtained different results.

It can be observed that the difference between the average accuracy obtained from the two main methods is very small (about 3,39% for the overall accuracy performance and 1,95% for the average class performance). However, in the second process, this difference may be related to spatial differences existing between the 2 maps, since the map obtained from the computer still presents some rectification problems.

Some problems concerning the misclassification of Pinus silvestris occurred due to the similar spectral reflectance of other coniferous stands near the city of Freiburg (see Figure 49).

It was observed that the type of confusion table applied in this study was a good indicator of the precision obtained in the mapping. However, especially working with satellite imagery, attention must be paid in order to avoid spatial distortions between the two compared maps. Working with the total values of both maps (computer and ground truth) seems to be the most accurate procedure once final results instead of partial ones (including commission and omission errors) are compared.

For test area 2

Test area 2 is entirely situated in rugged terrain. Nevertheless, the relative overall accuracy performance obtained was considerably high (93,94%), as shown in Table 23.

Table 23. Supervised Classification - Test Area 2.

Level of Accuracy	Forest Type	Computer % of the total scene	Ground Truth %	Error %	Average Class Classification
I	Coniferous (mixed)	12,78	14,82	- 2,02	86,23
	Deciduous (mixed)	21,43	11,62	+ 9,81	54,22
	<u>Picea abies</u> (pure)	62,98	73,09	-10,11	86,17
II	<u>Pinus silvestris</u> (pure)	2,79	0,47	- 2,02	16,84

Error difference

= - 6,06%

Overall Mapping Accuracy Performance = 93,94%

Average Class Classification = 60,85%

Table 24. Confusion table used for test area 1 (Unsupervised Classification)

Forest Type-Fig. 50	Test squares n	Test Squares classified as Type				Correct Classification n = %	Omission n = %
		7	5	6+8+9	4		
7	100	70	15	0	15	70	30
5	100	0	87	0	13	87	13
6+8+9	100	0	0	87	13	87	13
4	0	0	0	0	0	-	-

Comission
n = %

0 15 0 41

Inventory
Result n

300 70 102 87 41

Deviation of
n

-30 +2 -13 +41

Average accuracy performance

81,33

On the other hand, however, the average class performance was relatively low (60,85%). This is mainly due to the low accuracy classification obtained in the Pinus silvestris stands. In fact, the percentage of these stands in relation to the total classification (0,47%) is practically negligible if one considers surveying at reconnaissance levels.

Without the errors introduced into the classification by the small P. silvestris stands, the average class accuracy performance would have been 75,52% - namely, 14,67% higher than the actual results. In addition, the areal distribution of these stands is very small (42,66 ha.) when compared, for instance, with Picea abies (about 4.191,67 ha.).

When considering only the level I classification, an accuracy of 70,195% was obtained, but when level II was considered, the mapping performance decreased to 51,505% (a difference of about 18,69%). This is why the overall accuracy performance of 93,94% (relatively high) must be accepted with some care.

The low accuracy performance obtained from deciduous stands is difficult to understand or explain. It is possible that young stands were "confused" with green grass areas - namely, that grass areas were interpreted as deciduous. This is especially likely in steep terrain transitions, where the spectral characteristics of grass and deciduous stands are very similar and where the boundary delineation is sometimes difficult to carry out, even visually.

11.3.2. Unsupervised Minimum Distance Classification (MD)

In an attempt to estimate the average precision of the unsupervised MD classification, the same procedure was used as previously. The methodology as well as the number of classes remained the same, and the results are illustrated in Table 24.

In the coniferous stands, spectral distortions were verified, especially when their mixture with deciduous stands was higher than 10%.

It can be clearly seen that the difference in the average accuracy performance between supervised and unsupervised methods for this test area is relatively small (6%). Possibly, this difference is negligible in practice, depending on the application's objective (see Tables 22 and 24).

In spite of presenting better quantitative results in the supervised classification, the omissions and commissions were higher in the case of the unsupervised classification (compare Tables 22 and 24).

The supervised method is, of course, more operational since it furnishes, either directly or indirectly, the areas corresponding to the mapped resources and since the error control can be made in an interactive process. However, if the selection of training sets is not of good quality, many errors can be introduced into the classification.

11.4. Units of Intensive Forest Management

An area of about 1000 ha. was selected in order to analyse the potentials of computer assisted classification of Landsat data for intensive forest management plans. A very detailed mapping was carried out according to forest type, age and crown closure.

The area selected was situated in the upper Rhine valley. The dominant species was Pinus silvestris, occurring in ages ranging from 5 to 60 years (with the average stands being middle-aged). Their composition ranged from 40% purity (classified as mixed-forest) to 100% (pure stands). In the same way, deciduous stands of different species and degrees of composition were also present.

By analysing both supervised and unsupervised classifications one can verify that with supervised classifications it was only possible to separate P. silvestris from deciduous, independent of the cover density and age class (This problem was discussed earlier). In the unsupervised procedure the differences were more accentuated.

P. silvestris stands with densities smaller than 50% were displayed in a dark green color, even if the rest of the stand was composed of other conifers. An example of this is illus-

trated by a 35% density P. silvestris stand and 65% density Picea omorika stand in the test area. In the deciduous stands the older and denser the stands the darker yellow their colors. Stands with less than 30% crown density were very light yellow (almost white). Those with between 30-50% density were dark yellow and those above 50% density were greenish, especially when mixed with P. silvestris (very dark green). In this case, the younger the stand, the greater the influence of soil reflection upon the spectral signature. Consequently, its appearance in the classification was lighter.

On this study area, deciduous stands located in mountainous areas (considering that their closure degree and age were homogeneous) were displayed in a characteristic green color, while stands of similar composition, age and density situated in the valley were displayed in a darker green. Stands with densities of around 50% coniferous and 50% deciduous presented a light brown color. If the coniferous percentage in the mixture was somewhat greater, the color was red and if smaller ($\pm$ 10-15%) light brown to almost yellow. P. abies stands with densities higher than 90% and age classes greater than 40-50 years were easily recognized by their dark blue color.

The classifications derived from this study are only tentatively recommended for intensive management purposes, since the information provided by these classifications is insufficient for intensive management needs. Even in easily interpreted areas (such as in the present case), the obtained information, if not sufficiently controlled, can become quickly "confused". It can happen, for example, that young deciduous stands are interpreted as cultivated areas and vice versa. Consequently, for intensive management areas, it seems better to recommend work at reconnaissance levels.

Although it was possible in the present study to observe isolated stands with areas between 0,5 and 1,0 ha., it was not possible, unfortunately, to make positive visual identification of these stands. Naturally, this can be disappointing when

the desire is to achieve a higher degree of mapping accuracy.

11.5. Final Considerations about the Computer Assisted Classifications

Problems in the supervised procedure were created by small homogeneous spots of certain species from which it is not possible to extract representative training sets. These areas were either not classified or else incorporated into the class of the nearest spectral signature (Maximum Likelihood). Naturally, this introduced many errors into the mapping.

In the unsupervised procedure these "spots" were even more visible (at least in eight of the different classifications carried out in the area of study).

Once a basic knowledge of the different phytogeographic units occurring in the region has been acquired, the process of identification of the different classifications is relatively easy. In the test areas, this was especially noticeable with deciduous stands of different age and crown closure classes which could be observed in the unsupervised procedure but not in the supervised one. The reason for this is that in the supervised procedure the computer is trained to recognize "trained types" - namely, types with spectral signatures similar to those of the training sets. In the unsupervised procedure, all the different classes are clustered according to their spectral signatures, thereby making the formation of many classes possible.

Analysing these results, it is easy to understand why LECHI (1977) stated that "at the present moment the unsupervised classifications are the most used techniques for automatic pattern recognition of the objects on the ground, particularly concerning land use applications".

Summarizing, it can be concluded that computer assisted mapping in areas like the present one is not easy to accomplish, especially if a high degree of accuracy is required. Topography

plays an important role in the results and also makes the extraction of reliable training sets difficult.

The obtained results show that in areas similar to the present one only reconnaissance surveys could be performed using Maximum Likelihood classifications. Probably, a "cluster modified" procedure (see HOFFER et al, 1976) would have produced better results under these topographic conditions, but, unfortunately, this method was not available at DIBIAS of the DFVLR.

12. CONCLUSIONS AND RECOMMENDATIONS

Considering the results obtained in the present study area, the following conclusions can be made:

1 - Visual interpretation of black and white prints (1:200,000) has given little information concerning detailed forest typing. However, coniferous and deciduous in bands 5 and 7 could be separated in almost 100 per cent of the cases.

As far as it was investigated in this study, multirate imagery did not add sufficient information to justify its application in such a method of interpretation, but the season of the year must be carefully selected.

2 - The interpretation of Color Composites produced by color additive viewers, besides being easier, added more information for forest typing and their accuracies (boundary delineation) were similar to visual interpretation.

3 - The use of linear regression equations for forest acreage estimation was statistically significant and when constructed with a representative number of samples of the population, can be very useful for prediction plans. However, these equations seem to have only local application.

4 - Most of the microdensitometric measurements were very useful in forest typing (under very controlled conditions). Change in crown closure and age classes, as well as the overall structure of the different stands, could be detected in the microdensograms; though these changes were not visually observed, the differences were statistically significant.

5 - In test area 1 (flat and mountainous terrain) the supervised method of Maximum Likelihood classification was somewhat more accurate than the unsupervised (Minimum Distance Classification) - 6% - and was also more operational. However, in areas similar to the present one where many small homogeneous stands are cultivated, it is sometimes difficult to extract

representative "clean" training set statistics for supporting the supervised approach. In this case, the unsupervised method is very useful for obtaining an overall complete view of the entire area. The more complex the vegetative cover, the more difficult the phase of extracting representative training sets.

6 - In test area 2 (mountainous terrain), in spite of the high overall mapping accuracy (93,94 %), the average class classification was very low (60,85%). Relief played a very important role in these results. The cluster-modified method of automated classification seems to be indicated in this case.

7 - Qualitative evaluations of non-supervised classifications for studying intensive forest management units (level II) seem to be promising in flat areas. However, in rugged terrain, "isolated stands" with areas between 0,5 - 1,0 ha. could be observed but their identification could not be accomplished. This can bring disappointments when one is attempting to map forest resources with a higher level of accuracy.

8 - The great advantage of Landsat interpretation by computer assisted methods for forest maps lies in the following relation: Cost of information extraction/basic data per Km^2 /Time of information extraction. Taking for example the total area of the present study (about 121.670,00 ha.) and considering Color Infrared Airphotos at a scale of 1:10,000, the ratio is approximately DM 19,00/ Km^2 /200 days of work (field and laboratory work*). For Landsat computer assisted interpretation, the relation is approximately DM 1,1/ Km^2 /45 days of work (with 20 per cent of the area covered by sample plots).

* - field work consists of tree identification, relascopy for measuring diameters at breast height and height of dominant trees.

9 - One of the solutions for classifying forest types in areas similar to the present one, seems to be a combination of color composites obtained through color viewers (used for preparing the basic interpretation with the support of aircraft data from some "key-areas") and microdensitometric measurements of

some "very controlled" test areas.

The most operational method (but a more expensive one) is forest typing by means of a supervised Maximum Likelihood classification.

10 - Recommendations: According to the conclusions obtained from this study, the following model is suggested for monitoring or forest typing studies in areas with characteristics similar to the present one:

- a - Visual interpretation of Landsat MSS color composites (scale 1:200,000) with preliminary delineation of broad forest types;
- b - Separation, as far as possible, of the different broad forest types into strata according to crown closure following acreage estimation of the strata;
- c - Sampling Proportional to Size, or Proportion with distribution of $n_1, n_2, n_3, \dots, n_n$ square samples per stratum, each sample corresponding to a color infrared airphoto at a scale of 1:10,000;
- d - Detailed interpretation of every sampling plot (one aerial photo corresponding to an area of 529 ha.) with extraction of all training set statistics through microdensitometry - normally made in phase g;
- e - Extraction in every plot of the necessary forest statistics on the ground, using adequate sub-sampling methods;
- f - Reformulation of the preliminary broad classification (see item a) and extrapolation of results to the whole area per stratum, or,
- g - Supervised classification at a previously established scale (if software and hardware are available) instead of microdensitometric measurements;
- h - Extrapolation of results to the whole area;
- i - Tabulation of forest statistics (acreage, basal areas, volume per stratum, number of commercial trees per hectare, etc.) for the whole area per stratum; if necessary, regression models or another statistical

model, for acreage and volume estimation must also be constructed.

As illustration of the suggested statistical scheme, see Figure 51.

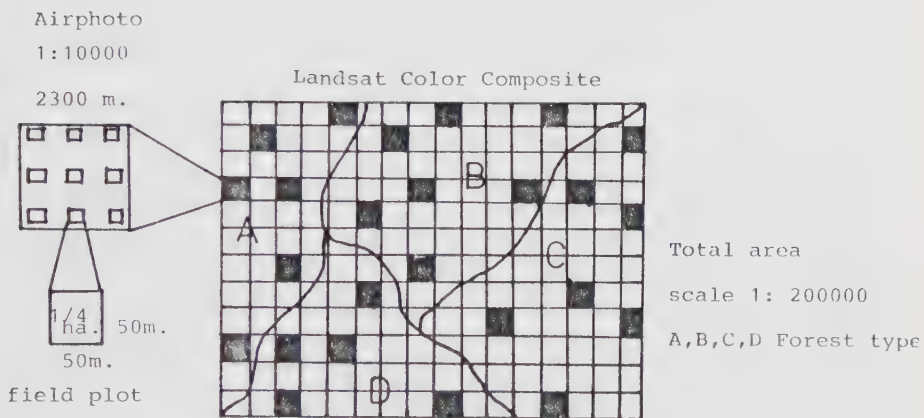


Figure 51. Illustration of a three stage inventory model suggested for the area of study

13. SUMMARY

The purpose of the present study was to investigate the potentials of Landsat MSS data for forest cover mapping in areas of intensively managed forest units.

The investigation was conducted in the southern region of the Federal Republic of Germany and dealt with an area of approximately 121,670 ha. This area was located around the city of Freiburg and included both flat sections of the Rhine Valley as well as rugged sections of the Black Forest.

Basically, five methods of interpretation were applied. The first used conventional visual interpretation of Landsat MSS black and white paper prints (1:200,000). The second made use of color infrared composites (1:310,000) produced through an Additive Color Viewer, Model 6000 - I²S. The third employed a Macbeth densitometer where, by analyzing the spectral responses of the different forest types (via photographic tone densities) the influence of the exposition slope upon the spectral response of each forest type and in each band was investigated. The fourth considered the results obtained from the Macbeth densitometer and used these results to select test areas of which microdensograms could be produced through a Joyce and Loebel microdensitometer, Model 3CS. Eventually, six test-strips were selected, and from these, 24 microdensograms were produced corresponding to the four Landsat MSS bands. The fifth and final method was a computer assisted one. Supervised and unsupervised classifications of two test areas were produced and these were qualitatively and quantitatively analyzed.

From the results obtained from these methods, it was concluded that the visual interpretation of Landsat MSS paper prints generally offered little information for consistently separating forest types (despite its use in separating coniferous and deciduous stands in almost 100 per cent of the cases in bands 5 and 7 in the area of study).

As far as it was investigated in the present study area, multi-temporal images did not add enough necessary information to justify their utilization. However, the season of the year should be carefully selected in each individual case.

Color composites proved to be more consistent and reliable for forest typing, besides being easier to interpret.

Linear regression equations (both simple and multiple models) were of practical importance in estimating the acreage of forested areas.

Most of the microdensitometric measurements were also very useful for consistently identifying forest types.

In the computer assisted classification phase, the supervised approach was 6% more accurate than the unsupervised and was also more operational. For rugged terrain, however, the unsupervised approach had certain advantages due to the difficulty of extracting the "clean" training set statistics needed for supervised classifications. The modified cluster method seems to be a helpful solution for areas located in such rugged terrain.

Finally, the most evident advantage of Landsat MSS automatic classifications, lies in their cost when compared with classifications carried out using aerial photography - namely, automatic interpretations are 18 to 19 times cheaper per Km^2 . Also, automatic classifications are 4 to 5 times faster when compared with color infrared airphotos of the same area (considering the same level of accuracy).

In any case, local experience of forest types is a factor of decisive and utmost importance.

14. ZUSAMMENFASSUNG

Das Ziel der vorliegenden Arbeit (Dissertation) war es, die Eignung von Landsat-MSS-Daten zur Kartierung von Waldgebieten in intensiv bewirtschafteten Bereichen festzustellen.

Die Untersuchungen wurden durchgeführt in einem Gebiet von ca. 121.670 ha. im Süden der Bundesrepublik Deutschland, nahe der Stadt Freiburg, sowohl in der flachen Rheinebene als auch in den hügeligen Gebieten des Schwarzwaldes.

Die Untersuchungen basieren auf der vergleichenden Anwendung fünf verschiedener Interpretationsmethoden:

- visuelle, konventionelle Interpretation von Landsat Schwarz-Weiß Papierabzügen im Maßstab 1:200.000
- Auswertung von Farbinfrarot-Kompositen, die mit einem Farbmischprojektor, Modell 6000 I²S hergestellt wurden (Maßstab 1:310.000)
- Auswertung mit Hilfe eines Macbeth Densitometers, wobei das spektrale Reflexionsverhalten der verschiedenen Waldtypen und der Einfluß der verschiedenen Hangexpositionen auf das Spektralverhalten der betreffenden Waldtypen in allen vier Spektralbereichen des Landsat-Multispektralscanners analysiert wurden
- unter Verwendung der Densitometermessungen wurden Testgebiete ausgewählt, die mit Hilfe eines Mikrodensitometers, Joyce-Loebl JCS, eingehender untersucht wurden. Von sechs Teststreifen wurden, entsprechend den vier Landsat-Kanälen, 24 Mikrodensitogramme erstellt. Die Teststreifen entsprechen Forstbeständen verschiedener Struktur (Alter, Kronenschlußgrad etc.).
- schließlich wurden mit Hilfe des digitalen Bildauswertesystems DIBIAS der DFVLR von zwei Testgebieten kontrollierte und unkontrollierte, computergestützte Klassifizierungen durchgeführt und qualitativ und quantitativ ausgewertet.

Eine abschließende Bewertung der erzielten Ergebnisse zeigte, daß die visuelle Interpretation von Landsat-S/W-Papierabzügen kaum eine zuverlässige Unterscheidung der verschiedenen Wald-

typen ermöglichte, abgesehen von der Trennung von Laub- und Nadelwaldbeständen, die in den Kanälen 5 und 7 in nahezu 100% aller Fälle möglich war.

Die multitemporale Auswertung erbrachte keine Verbesserung, die den Mehraufwand rechtfertigen könnte; dennoch muß die Jahreszeit der Aufnahme sorgfältig ausgewählt werden.

Farbkompositen erwiesen sich als geeigneter und zuverlässiger zur Unterscheidung von Waldtypen und waren darüberhinaus leichter zu interpretieren.

Lineare Regressionsgleichungen, sowohl einfache als auch multiple Modelle, zeigten große praktische Bedeutung für die Schätzung von Waldflächen.

Mikrodensitometrische Messungen waren ebenfalls sehr hilfreich zur Identifizierung verschiedener Waldtypen.

Bei der computergestützten Klassifikation erwies sich die kontrollierte Klassifizierung als geringfügig genauer (6%) verglichen mit der unkontrollierten Klassifizierung, die allerdings weniger aufwendig ist.

Im hügeligen Gebiet zeigten sich allerdings einige Vorteile der unkontrollierten Klassifikation, da die Schwierigkeiten, die mit der Auswahl geeigneter Testgebiete zur Gewinnung der für eine kontrollierte Klassifikation erforderlichen statistischen Daten verbunden sind, durch dieses Verfahren umgangen werden können.

Die modifizierte Clusteranalyse scheint eine günstige Lösung für die Klassifizierung solch hügeliger Gebiete zu sein.

Der bedeutendste offensichtliche Vorteil der computergestützten Auswertung von Landsat-Daten ist darin zu sehen, daß im Vergleich zur Auswertung von Luftbildern etwa um den Faktor 18-19 geringere Kosten je Km^2 anfallen; darüber hinaus war die Auswertung etwa 4-5-fach schneller zu bewerkstelligen, verglichen

mit der Auswertung von Farbinfrarotbildern des gleichen Gebietes (wobei gleiche Genauigkeitsanforderungen vorausgesetzt wurden).

Besonders ist hervorzuheben, daß die Kenntnis der örtlichen forstlichen Gegebenheiten eine wesentliche Voraussetzung für eine optimale Auswertung der Landsat-Daten ist.

15. RESUMO

O objetivo do presente estudo foi estudar a potencialidade das imagens multiespectrais dos satélites Landsat, para aplicação em estudos de monitoramento da cobertura vegetal, em áreas com características de manejo intensivo, como a maioria das áreas florestais da Europa.

O estudo foi conduzido no sul da República Federal Alemã, na região de Baden, em área com aproximadamente 121.670 ha. situada em torno da cidade de Freiburg, tanto sobre a planície do Alto Reno, como em relevo acidentado da Floresta Negra.

Basicamente, cinco métodos de interpretação foram aplicados;

O primeiro, através de interpretação visual convencional, utilizando-se cópias de imagens Landsat-MSS em preto e branco na escala 1:200,000.

O segundo método, utilizando-se de um "Color Additive Viewer" modelo 6000 da I²S, onde quatro transparencias em preto e branco correspondentes aos quatro canais MSS foram utilizadas, produzindo-se inúmeras composições coloridas na escala 1:310,000.

O terceiro método fez uso de um densitometro MacBeth onde, analisando-se respostas espectrais - via densidade de ton fotográfico de diferentes coberturas florestais, em diferentes áreas-teste, procurou-se determinar, estatisticamente, a influencia da encosta de exposição sobre a resposta espectral do tipo florestal.

Para o quarto método, utilizou-se os resultados obtidos na estapa anterior, procurando-se selecionar através de aerofotos e trabalho de campo, áreas teste, onde fossem produzidos microdensogramas através de um microdensitometro Joyce and Loeb1 modelo 3CS. Seis áreas-teste foram selecionadas, correspondendo a tipos florestais diferentes, apresentando, cada uma, idades e densidades de cobertura também diferentes. Vinte e quatro

microdensogramas foram produzidos e, de cada um, os valores mínimos, máximos, médios e desvio-padrão das densidades de ton foram calculados. Posteriormente, um teste múltiplo de "t" determinou as diferenças entre as faixas-teste e, entre os quatro canais utilizados.

O quinto método foi desenvolvido nas instalações de Instituto de Pesquisas Aeroespaciais da Alemanha em Oberpfaffenhofen, nas proximidades de Munique; para isso, as facilidades do programa DIBIAS (Soft e Hardware) foram utilizadas. Nesta fase, utilizou-se Fitas Magnéticas Compatíveis com Computador (Computer Compatible Tapes) das cenas Landsat, produzindo-se classificações não-supervisionadas e supervisionadas de duas áreas-teste situadas nas cercanias de Freiburg. Uma área situada entre a planície do Aito Reno e a Floresta Negra e, a outra, localizada inteiramente em relevo acidentado da Floresta Negra, em uma tentativa de se estudar o efeito do relevo sobre as classificações efetuadas.

As imagens estudadas foram tomadas em 9 de Agosto de 1975.

Toda a área de estudo foi detalhadamente mapeada utilizando-se como material básico, fotografias infravermelhas coloridas na escala aproximada 1:11,000. Adicionalmente, imagens infravermelhas em preto e branco de um varredor (scanner) multi-spectral tomadas em diferentes escalas foram utilizadas.

Dados sobre classes de idade, classes de altura, composição, volume, etc. de todos os povoamentos da área foram cedidos pelos Serviços Florestais da região, tornando o mapa utilizado como "verdade de Campo" o mais perfeito possível.

Considerando os resultados obtidos para a área de estudo conclue-se:

1 - A interpretação visual de imagens Landsat MSS em preto e branco (1:200,000) forneceu pouca informação com relação, a identificação de espécies florestais contudo, coníferas e folhosas puderam ser separadas em quase 100 por cento dos

exemplos na imagens dos canais 5 e 7.

As imagens multi-temporais não adicionaram suficientes informações que justificassem seus usos, contudo, a estação do ano deve ser criteriosamente selecionada.

2 - A interpretação de composições coloridas, além de ser mais fácil, forneceu mais informações sobre identificação de espécies.

3 - O uso de equações lineares de regressão para estimativa de áreas de povoamentos florestais, via Landsat, foi estatisticamente significativa, contudo, apresentam caráter local.

4 - Microdensogramas foram muito úteis na identificação de tipos florestais. Alterações na estrutura de cobertura de copa e nas classes de idade e, que não puderam ser constatadas visualmente, puderam ser detectadas e analisadas nos microdensogramas (as diferenças foram estatisticamente significantes).

5 - O método supervisionado de classificação automática foi 6 por cento mais preciso do que o não-supervisionado, além de ser mais operacional. Contudo, em áreas como a presente, onde existe grande quantidade de pequenos e homogêneos povoamentos, é difícil extrair estatísticas "puras" desses povoamentos para apoiar e programar o computador na classificação supervisionada. Neste caso, o método não-supervisionado mostrou ser muito útil na obtenção de um quadro total da área em estudo.

Quanto mais complexa for a cobertura florestal, mais difícil é a fase de extração ou seleção de áreas de treinamento (training sets) para apoiar as classificações supervisionadas.

6 - As avaliações qualitativas de classificações não-supervisionadas em área de manejo florestal intensivo são promissoras. Contudo, só para terrenos planos. Em áreas de topografia acidentada, "povoamentos isolados" cujas áreas situavam-se entre 0,5 - 1,0 ha. muito embora fossem observados, não puderam ser consistentemente identificados.

7 - A grande vantagem das interpretações automáticas de cenas

Landsat para produção de cartas florestais, reside na relação: "Custo de extração de informações e dos dados básicos por Km^2 /Tempo necessário para extração das informações". Considerando, por exemplo, a área total do presente estudo (approx. 121.67,00 ha.): Para aerofotos infravermelhas na escala 1:10,000, a relação é DM 19, Km^2 /200 dias de trabalho (campo e laboratório). Para Landsat a relação é aproximadamente DM 1,1 Km^2 /45 dias de trabalho (20 por cento da área coberta com amostras de campo).

8 - A solução mais efetiva para áreas semelhantes a presente consiste na combinação de composições coloridas obtidas através de Visores (Viewers) que serão utilizadas na preparação da interpretação básica com ajuda de aerfotos de algumas "áreas-chave", e medições microdensitométricas de algumas áreas para correta identificação dos tipos florestais envolvidos, especialmente, em áreas de difícil interpretabilidade.

A solução mais operacional, contudo, a mais cara, consiste no mapeamento através de um método supervisionado de classificação automática.

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17. VITA

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